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Determination of Radium Removal Efficiencies in Iowa Water Supply Treatment Processes

Iowa Dept of Environmental Quality, Des Moines

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DETERMINATION OF RADIUM REMOVAL EFFICIENCIES IN IOWA WATER SUPPLY TREATMENT PROCESSES

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The study included sampling and analysis of waters from nine municipal water treatment plants in the State of Iowa to determine the efficiency of radium-226 removal in a variety of treatment processes and to provide cost data for these processes. Supplies with a high naturally occurring radium content over 5 pCi/l in Jordan and Dakota sandstone formation well waters were selected and included four different treatment processes: reverse osmosis, iron removal filtration, sodium ion exchange, and lime-soda ash softening. Analyses were performed to determine radium, hardness, and other parameters on the well water and removals of these parameters through the treatment process.

Radium-226 removals through the reverse osmosis, sodium ion exchange, and lime-sode ash softening plants were in the range of 95% removal. Radium removals in the iron removal plants ranged from 12 to 38%.

Total annual capital and operation costs and plant operation and maintenance costs are included but were highly variable and typical cost data could not be developed.

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by

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April 1976

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PREFACE

The Office of Radiation Programs of the U.S. Environmental Protection Agency carries out a national program designed to evaluate population exposure to ionizing and non-ionizing radiation, and to promote development of controls necessary to protect the public health and safety. This report was prepared in order to determine the natural radioactivity source terms associated with radium in water supplies and the radium removal efficiencies in water treatment processes. Readers of this report are encouraged to inform the Office of Radiation Programs of any omissions or errors. Comments or requests for further information are also invited.

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Director
Technology Assessment Division (AW-459)
Office of Radiation Programs

ABSTRACT

The purpose of the study was to sample and analyze waters from nine municipal water treatment plants in the State of Iowa to determine the efficiency of radium-226 removal in a variety of treatment processes and to provide cost data for these processes. Supplies with a high naturally occurring radium content over 5 pCi/l in Jordan and Dakota sandstone formation well waters were selected and included four different treatment processes: reverse osmosis, iron removal filtration, sodium ion exchange, and lime-soda ash softening. Analyses were performed to determine radium, hardness, and other parameters on the well water and removals of these parameters through the treatment process.

Radium-226 removals through the reverse osmosis, sodium ion exchange, and lime-soda ash softening plants were in the range of 95% removal. The hardness removals with reverse osmosis and ion exchange processes were generally nearly identical to the radium removal. The shortage of soda ash during the course of the study caused considerable variation in hardness and radium removals in the lime-soda ash softening process, but generally, the radium removals were greater than the hardness and iron removals. Radium removals in the iron removal plants ranged from 12 to 38%.

Total annual capital and operation costs and plant operation and maintenance costs are included but were highly variable and typical cost data could not be developed.

This report was submitted in fulfillment of Contract No. 68-03-0491 by the Iowa Department of Environmental Quality under sponsorship of the Environmental Protection Agency. Work was completed as of June 4, 1975.

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SECTION I

SUMMARY AND CONCLUSIONS

On the basis of the literature search and chemical and radiological data obtained from the nine public water supplies in this study, the following conclusions are drawn:

1. High radium-226 water is associated primarily with the deep Jordan sandstone formations (1000-3200 ft. deep) principally in southern Iowa and with the Dakota sandstone formation (100-600 ft. deep) in northwestern Iowa. Other studies by the State of Iowa and other states indicate that surface waters have mean radium-226 concentrations of only 0.10 pCi/l.

   Radium-226 content of raw well water at the nine water treatment plants studied ranged from a low of 5.7 pCi/l in a Dakota sandstone formation to a high of 49 pCi/l in a Jordan sandstone formation.

2. Table I summarizes the radium-226 removal efficiency compared with the concurrent iron and hardness removal efficiencies through plant units. The divalent radium-226 removals, in general, parallel the hardness, calcium and magnesium removals.

   a. Reverse Osmosis - Overall removal of radium-226 was 96% as compared with a concurrent hardness removal of 95% through a battery of hollow fiber permeators at a product recovery of 69 percent, or the percent conversion of treated water produced to well water pumped. Other corresponding chemical constituent removals were calcium, 95%, iron, 81% and total solids, 92%. The literature indicates that the membrane rejection of divalent ions such as Ca and Mg is greater than for the monovalent ions Na and Cl and the study indicated the same conclusion.

   b. Iron Removal - Two of the water treatment plants utilized iron removal only and all four zeolite softening plants used iron removal for pretreatment. Radium-226 removal through the iron removal units varied from a low of 12% using aeration, short term aeration and iron filters to a high of 38% through aeration, short term detention and continuous regene-ated potas sium permanganate greensand filter. The concurrent iron removal efficiencies were 85% and 98%, respectively. The manner of radium removal is possibly adsorption or catalytic action by the oxidation products deposited on the filter media. In one survey at Estherville when an excessive quantity of water was passed through the iron removal filter

TABLE 1
Radium-226 Removal Efficiency
Comparison with Iron Hardness Removal Efficiencies

Percent Removals Through Plant Units

	Iron Filter		Softening		Sand Filter		Overall		Well
	Ra-226	Iron	Ra-266	Hardness	Ra-266	Hardness	Ra-226	Hard.	Ra-226
Municipality	%	%	%	%	%	%	%	%	mg/1
Greenfield-RO			96	95			96	95	14
Adair Greensand	38	98							13
Stuart Iron Filter	25	97							16
Eldon	12	85	96	97			96	97	49
Estherville	11	81(1)	94	95			95	95	5.7
Grinnell	15	42(2)	97	97			97	97	6.7
Holstein	28	97	93	97			96	98	13
Webster City(3)									
Clarifier #1			68	32	60	15	85	48	6.1
Clarifier #2			57	43					
Webster City(4)									
Clarifier #1			88	69	50	29	96	78	7.8
Clarifier #2			96	69					
West Des Moines			72	43	10(5)	12	75	50	9.3

(1) Poor removal due to long filter run.
(2) Aeration & settling only; no filtration.
(3) Lime softening only; no soda ash.
(4) Lime-soda ash treatment.
(5) Poor solids removal through filter selected.

both the iron and radium concentrations in the filter effluent near the end of the filter run were greater than that in the filter influent.

c. Sodium Cation Exchange Softening - Radium-226 removals were excellent with the four sodium cation exchangers removing 93 to 96 percent of the radium while also removing 95 to 97 percent of the hardness.

   Two of the ion exchange softeners were run 10 percent past the normal regeneration time to determine radium removal as the exchange media was nearing complete exhaustion. The data indicated radium removal continuing after hardness removal capacity was exhausted.

   In all of the ion exchange softener installations 6 to 25 percent unsoftened water was bypassed around the softener and blended with the finished water being pumped to the distribution system to provide sufficient calcium carbonate for deposition of a protective coating on the water mains.

d. Lime-Soda Ash Softening - Overall removal of radium-226 by softening and filtration can reach the 95 percent removal range of the reverse osmosis and ion exchange processes if hardness removal approaches 75-80%. Considerable variations in radium removals were noted depending on chemical dosage, pH range, magnesium removal, non-carbonate hardness removal and filtration efficiency.

   The use of soda ash in normal plant operation was restricted due to a shortage of the chemical. A second survey conducted at Webster City when soda ash became available indicated average radium and hardness removals of 92 and 69 percent respectively in a primary upflow basin. A pH level of 10.85 during this survey may have contributed to better removals when compared with 10.1 pH levels in the two previous surveys.

   Further solids removals by filtration gave a unit removal as high as 50 percent for radium and 29 percent for hardness. This removal of the unsettled softening precipitates was obtained from a filter passing only 2 turbidity units in the effluent. Poor radium and hardness removals were obtained from a filter with poor turbidity removal.

3. Table 2 is a summary of the concentration and percent removals of Ra-226, hardness and iron by the various treatment processes employed by the nine municipal plants. Radium concentrations in

Table 2
Summary Ra-226 Hardness and Iron Removals By Process
Concentration and Percent Removal

Sampling Point	Ra-226 pCi/l	%	Hardness mg/l	%	Iron mg/l	%	Ra-226 pCi/l	%	Hardness mg/l	%	Iron mg/l	%
Iron Removal												
Adair							Stuart					
Well Supply	13				1.1		16				0.94	
Aeration-Detention	13	0			1.2	0	14	13			1.0	0
Iron Filter Eff	8	38			0.02	98	12	14			0.03	97
Overall		38				98		25				97
Zeolite Softening												
Eldon							Estherville					
Well Supply	49		375		2.0		5.7		915		2.0	
Iron Filter Eff	43	12	360		0.3	85	4.9	11	915		0.38	81
Softener Eff	1.9	96	10	97	0.05	83	0.3	94	46	95	0.05	87
Overall		96		97		97		95		95		97
Zeolite Softening												
Grinnell							Holstein					
Well Supply	6.7		385		0.71		13		920		1.8	
Aeration-Detention	5.7	15	387		0.41	42	10	23	870		1.6	11
Iron Filter Eff							7.2	28	885		0.05	97
Softener Eff	0.2	96	11	97	0.03	93	0.5	93	18	97	0.02	60
Overall		97		97		96		96		98	0.02	99
Reverse Osmosis					TS							
Greenfield					mg/l	%						
Well Supply	14		610		2160							
RO Plant Eff	0.06	96	29	95	164	92						
Overall		96		95	164	92						

	Ra-226 pCi/l	%	Hardness mg/l	%	Ra-226 pCi/l	%	Hardness mg/l	%	Ra-226 pCi/l	%	Hardness mg/l	%
Lime Soda Ash Softening												
	Webster City 8/13/74				Webster City 2/20/75				West Des Moines			
Well Supply	6.1		507		7.8		482		9.3		376	
Clarifier #1	1.9	68	333	32	0.9	88	150	69	2.6	72	215	43
Clarifier #2	2.6	57	282	43	0.3	96	150	69				
Sand Filter Effluent	0.9	60	260	15	0.3	50	106	29	2.35	10	190	12
Overall		85		48		96		78		75		50

the raw well water varied from a high of 49 pCi/l to a low of 5.7 pCi/l. Radium concentrations in the plant effluent varied from a high of 12 pCi/l in one of the iron removal plants to a low 0.06 pCi/l in the reverse osmosis plant. Percentage radium removals by the ion exchange process are in the 95-98% range for both high and low radium concentrations in the raw well waters.

Hardness concentrations in the raw well water varied from a high of 920 mg/l to a low of 375 mg/l. There was no correlation of high radium concentration with high hardness concentrations and the highest radium concentration was associated with the lowest hardness concentration among the supplies studied.

4. Radium-226 concentrations and total radioactivity at various stages of the treatment process were used to determine a material balance showing points of radium removal. Considering the difficulty in obtaining adequate flow measurements in some plants, generally good material balances were obtained.

As shown by the following data, there was a wide range of Ra-226 concentrations in the various waste waters during radium removal operations.

Ra-226 Concentration in Water Treatment Wastes

Range of Composite Samples - Values in pCi/l

Reverse Osmosis Reject Water	Iron Removal Filter Backwash	Ion Exchanger		Softener Sludge	Filter Backwash
		Backwash	Rinse		
43	80-636	7.8-94	114-1960	980-2300	50-90

5. With the exception of the lagooning of lime sludge and discharge of wastes from one ion exchange softening plant to a municipal lagoon, all wastes from the water treatment process are discharged to watercourses ranging from intermittent watercourses to high discharge streams. No complaints or reports of detrimental effects have been received by the municipalities or state regulatory agency regarding the discharges. Costs of treatment or removal of these water treatment plant wastes were not determined.

The following data indicate the wide range of concentration of the significant water treatment wastes produced by the various treatment processes.

Significant Water Treatment Waste Constituents

Concentrations in mg/l

Iron Filter Backwash	Ion Exchange Brine Rinse Range of Averages			Softener Sludge	Filter Backwash
Iron	Total Solids	Hardness	Chlorides	TS	TS
69-320	54,000 to 130,000	16,000 to 39,000	9,500 to 120,000	72,000 to 145,000	739 to 4700

Likewise the proceeding data give the wide range of Ra-226 concentrations in these wastes.

The iron removal filter backwash iron concentrations of 69 to 320 mg/l are largely suspended matter which is settleable and detention can be used to reduce the suspended solids content below the generally suggested discharge requirement of 20 mg/l. Sand filter backwash following lime softening had total solids concentrations up to 4700 mg/l and these wastes are also settleable and the supernatant reusable.

During the brine rinse of the ion exchange media, chlorides of calcium and magnesium and excess regenerant salt pass to wastes from the softener. The above table indicates the total solids (largely dissolved) increase to a range of 54,000 to 130,000 mg/l and the chlorides increase to a range of 9,500 to 120,000 mg/l in the brine rinse. The principle of mass action requires an excess of salt for regeneration and only the middle one-third of the brine rinse is high in sodium and might be used in some manner in subsequent regenerations.

Softening sludges from upflow clarifier basins varied from 7.2 up to 14.5% solids with both plants providing lagooning of these wastes. One plant has initiated pumping of softener sludge to a nearby cement plant which utilizes the sludge and added moisture in the production of cement.

6. Sampling of all Iowa public water supplies and compilation of all existing radiological data is not complete, but the data indicate that of 567 public supplies sampled, over 120 supplies exceed the existing radium-226 standard of 3 pCi/l as contained in the 1962 Public Health Service Drinking Water Standards. The same data indicates that an additional 144 supplies have values ranging between 0.5 and 2.9 pCi/l or a total of 224 supplies out of 567 municipalities exceeding a 0.5 pCi/l value.

7. Many sodium ion exchange softened waters where sodium replaces the calcium and magnesium may provide more sodium than is allowed from food on severely restricted diets of some patients suffering from congestive heart failure, hypertension and certain kidney and liver diseases. Likewise there have been many studies both here and abroad suggesting that low coronary heart disease was associated with hard water areas.

8. Total annual capital and operation costs were highly variable in a range of 44 to 132¢/1,000 gallons due to inclusion of distribution capital and operation costs which could not be separated from financial records. Plant operation and maintenance costs showed a range of 12 to 45¢/1,000 gallons. In general, the larger communities had lower unit costs.

SECTION 2

RECOMMENDATIONS

The project study indicated that radium-226 removals in the range of 95% could be consistently expected from the reverse osmosis and sodium ion exchange processes. Removal of radium-226 by the lime-soda ash softening process was quite variable due to differences in chemical dosages, operating controls and hardness removals. An additional study would be desirable to confirm correlation of removal of radium with other divalent ions.

The project study did not include a sufficient number of plants to determine reliable cost data. Capital and operational costs for radium removal and disposal of treatment wastes should be developed for a range of plants based on different population ranges. The type of waste materials generated from the reverse osmosis, ion exchange softening and lime-soda ash softening processes and the methods, economics and hazards of each disposal or storage method should be investigated.

Ultimate waste treatment and disposal requirements must be developed prior to a study of disposal costs.

Additional research is needed to confirm or refute a finding of an increased bone neoplasm mortality rate due to elevated radium-226 levels as indicated in such studies as the 1964 Iowa-Illinois epidemiological study.

Some suggestive evidence has indicated soft water is not as healthful as hard or mineralized waters. A review of research on the relations of heart disease to soft water suggests more definitive studies need to be undertaken to resolve the question. On the other hand, there is concern with sodium in drinking water with relation to congestive heart failure, hypertension and certain kidney and liver diseases.

SECTION 3

INTRODUCTION

This report and study were performed by the Iowa Department of Environmental Quality in response to a contract between the Department and the U. S. Environmental Protection Agency dated June 28, 1975, and is entitled "DETERMINATION OF RADIUM REMOVAL EFFICIENCIES IN IOWA WATER SUPPLY TREATMENT PROCESSES." The study is supported by the U. S. Environmental Protection by grant to the State of Iowa, Contract No. 68-03-0491. In turn the Iowa Department of Environmental Quality has contracted with the State Hygienic Laboratory University of Iowa to provide radiological and mineral analyses and technical consultation for completion of the radium removal study and the project report.

SECTION 4

OBJECTIVES

The primary purpose of the study was to sample and analyze potable waters from nine municipal water treatment plants in the State of Iowa to determine the efficiency of radium-226 removal in a variety of water treatment processes. The U. S. Environmental Protection Agency requires information on the efficiency and cost data in order to implement and develop the limit on radium-226 concentration in the revised drinking water standards to be promulgated under provisions of the Safe Drinking Water Act. High natural radium-226 concentrations are common in water from many middle west wells penetrating the deep sandstone formations of Ordovician or older age as well as the Dakota sandstone formation.

Under the study, nine municipalities with a high naturally occurring radium content over 5 pCi/liter in well water were selected which included four different water treatment processes: lime-soda ash softening, sodium cation exchange softening, reverse osmosis and iron removal filtration (including aeration and continuously regenerated greensand filters). Sampling for radiological and chemical analyses was performed to determine radium, hardness and other parameters on the raw deep well supply and their removal percentages or amounts through various stages of treatment processes. Samples were also taken on various discard waters, regeneration waters and treatment media to assist in determining the fate of the radium content through the treatment process.

A secondary objective was to determine capital and operating costs of the various treatment processes for substantial removal of radium from the high radium well waters.

SECTION 5

STUDY AND SAMPLING PROCEDURES

SELECTION OF WATER SUPPLIES

Public water supplies to be included in the study were selected on the basis of (1) a high raw water radium-226 content (greater than 5 pCi/l) (2) a variety of treatment processes (3) availability of continuous operation during the study and (4) a variety of municipal population served.

WATER TREATMENT PROCESSES

On the basis of including the four basic water treatment processes and securing representative examples of these processes the following Iowa municipalities were selected. A brief listing of pertinent water treatment units and the 1970 populations are included as follows:

(1) Reverse Osmosis

Greenfield - (2212 population) Deep well and three reverse osmosis permeators furnish portion of total consumption.

(2) Iron Removal

Stuart - (1354 population) Deep well, aerator, settling and four pressure iron removal filters.

Adair - (750 population) Deep well, aerator and two continuously regenerated greensand filters.

(3) Ion Exchange

Eldon - (1319 population) Deep well, aerator, pressure iron removal filter and two pressure ion exchange softeners.

Estherville - (8108 population) Deep well, aerator, gravity iron removal filters and four pressure ion exchange softeners.

Grinnell - (8402 population) Three deep wells, aerator, settling and three pressure ion exchange softeners.

Holstein - (1445 population) Deep well, aerator, settling, pressure iron removal filter and two pressure ion exchange softeners.

(4) Lime-Soda Ash Softening

Webster City - (8488 population) Two deep wells, aerator, two parallel upflow clarifiers, recarbonation and four gravity and sand filters.

West Des Moines - (16,441 population) Two deep wells, aerator, two series upflow clarifiers, recarbonation and gravity sand filters.

Figure 1 is a map of Iowa giving the general location of municipalities studied in the project.

SAMPLING PROGRAM

Samples were collected from wells furnishing the raw water supply and from various stages through the treatment processes to determine changes and removals of radium content and other pertinent chemical parameters. In addition to the radiological and chemical concentration, flows or other quantity data were obtained to determine whether plants were meeting design rates and to provide data for determining a material balance of radium-226 removals.

Wells

Samples were generally collected near the beginning of the pumping periods and following longer pumping periods to determine any time related variability in radium, hardness and other chemical parameters during pumping.

Aeration and Settling

Samples were collected of aerator effluents or effluents of settling units preceeding iron removal filters or zeolite softeners to determine radium-226, iron or other chemical parameter removals.

Iron Removal Filters

Samples were taken before and after filtration to determine removal efficiencies during various stages of the filtration cycle. Various types of composite samples of the filter backwash were collected to determine iron and radium loadings in the backwash water and radium removals by this treatment process during the filtration cycle.

Ion Exchange Softening

Samples were collected of the influent and of the effluent soon after regeneration, at 25% cycle, at mid-cycle, at the end of the softening cycle just before breakthrough and at 110% of the cycle following breakthrough. Additional samples were also collected from adjacent softeners at various stages in the regeneration cycle to check removal efficiencies of radium-226, hardness and other chemical parameters of all softening units.

Zeolite softener backwash was sampled by compositing and the flow measured to determine radium-226 content as a part of a material balance through this unit.

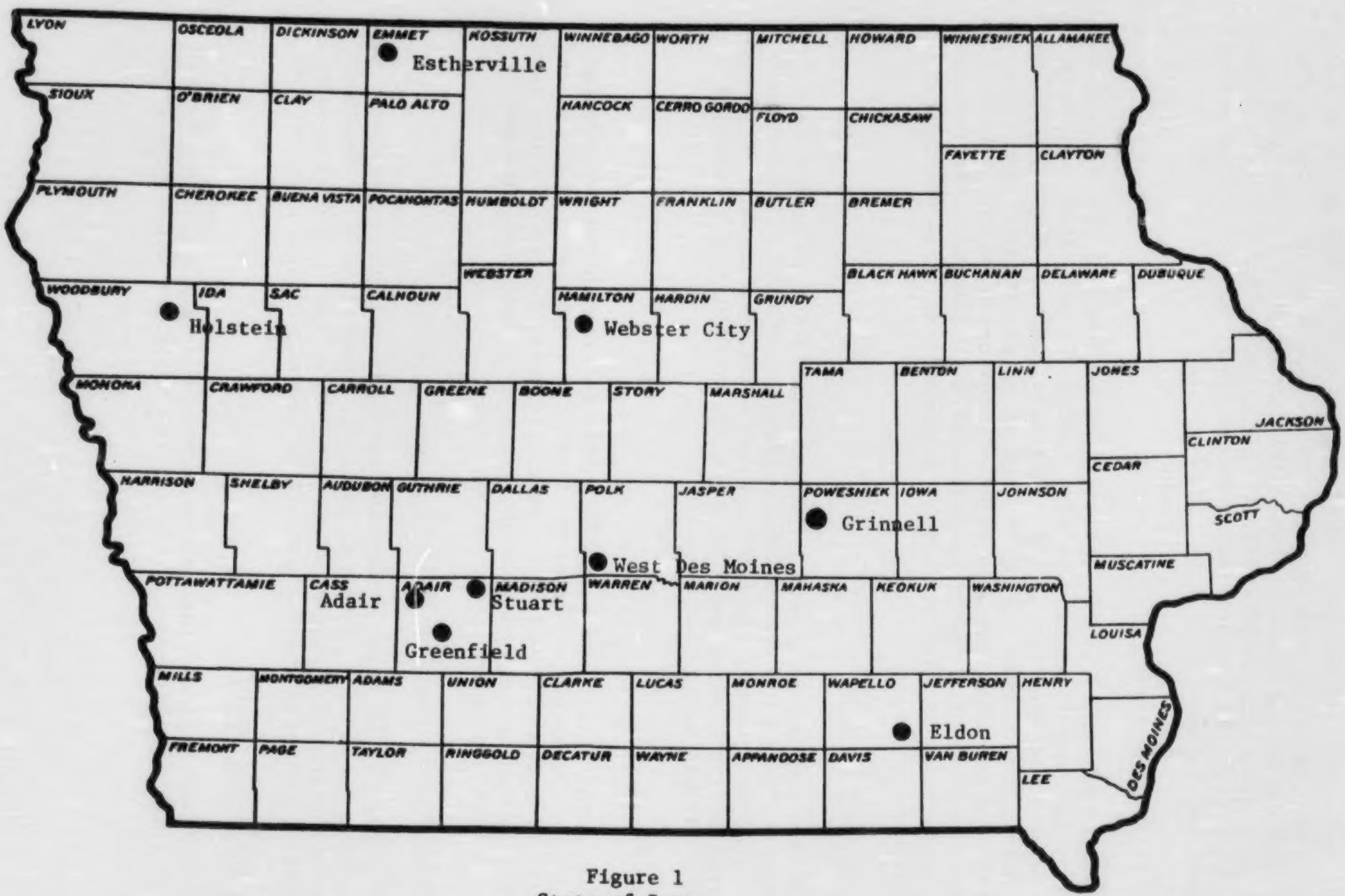

LYON
OSCEOLA
DICKINSON
EMMET
Estherville
KOSSUTH
WINNEBAGO
WORTH
MITCHELL
HOWARD
WINNESHIEK
ALLAMAKEE
SIOUX
O'BRIEN
CLAY
PALO ALTO
HANCOCK
CERRO GORDO
FLOYD
CHICKASAW
FAYETTE
CLAYTON
PLYMOUTH
CHEROKEE
BUENA VISTA
POCAHONTAS
HUMBOLDT
WRIGHT
FRANKLIN
BUTLER
BREMER
WEBSTER
BLACK HAWK
BUCHANAN
DELAWARE
DUBUQUE
WOODBURY
IDA
SAC
CALHOUN
HAMILTON
HARDIN
GRUNDY
Holstein
Webster City
MONONA
CRAWFORD
CARROLL
GREENE
BOONE
STORY
MARSHALL
TAMA
BENTON
LINN
JONES
JACKSON
CLINTON
CEDAR
HARRISON
SHELBY
AUDUBON
GUTHRIE
DALLAS
POLK
JASPER
POWESHIEK
IOWA
JOHNSON
Grinnell
SCOTT
West Des Moines
MUSCATINE
POTTAWATTAMIE
CASS
ADAIR
MADISON
WARREN
MARION
MAHASKA
KEOKUK
WASHINGTON
Adair
Stuart
Greenfield
LOUISA
MILLS
MONTGOMERY
ADAMS
UNION
CLARKE
LUCAS
MONROE
WAPELLO
JEFFERSON
HENRY
Eldon
DES MOINES
FREMONT
PAGE
TAYLOR
RINGGOLD
DECATUR
WAYNE
APPANOOSE
DAVIS
VAN BUREN
LEE

Figure 1
State of Iowa
Location of Water Treatment Plants
Radium Removal Efficiency Study

During the brine and rinse portion of the regeneration cycle composite samples were collected when an increased salometer (indication of % NaCl) degree reading indicated the regeneration brine and calcium and magnesium ions were present in the waste discharge of the softener. Curves were developed showing salometer degree, radium-226 and hardness during this brine rinse cycle and radium removal was calculated as part of a material balance.

Lime-Soda Ash Softening

Samples were collected of the influent and effluent of the suspended solids contact softeners to determine radium-226 and other parameter removals or additions through these clarifier units. Several samples were generally collected during the operating day to determine treatment efficiency variations. In addition, composite sludge drawoff samples were collected and volume calculated to determine the radium-226 and hardness removals and permit subsequent material balance calculations.

Filtration

Samples were collected of sand or anthrafilt filter influents and effluents to determine radium-226 removals as well as other chemical constituent reductions. In addition composite samples were collected of filter backwash and quantities recorded to determine radium-226 removals by this unit.

Reverse Osmosis

Raw and product water samples were collected from individual permeators and combined permeator effluent to determine treatment variations and removals of radium-226 and other chemical consitituents. Reject water from the permeator was measured and sampled to determine radium-226 and other chemical constituent concentrations.

TREATMENT PLANT CHARACTERISTICS

Complete details of plant design and operation including pertinent flow rates, unit capacities, chemical additions, description of treatment media, operating cycle times, storage volumes, well use during sampling and other procedures which might affect process efficiencies were obtained.

ANALYTICAL PROCEDURES

The Iowa State Hygienic Laboratory under the direction of Dr. R. L. Morris, Associate Director, performed the following analytical work.

Radiological

Gross alpha and radium-226. Radium-226 analyses were completed by co-precipitation with mixed barium and lead sulfates in accordance with Standard Method ASTM D 2460-70 with necessary modifications as shown in Appendix D. Calculations for the precision and accuracy of the radium analysis are also included in Appendix D.

Chemical

Slected samples were analyzed for complete mineral and trace metals in accordance with procedures contained in the 13th edition of "Standard Methods for Examination of Water and Wastewater". The majority of chemical determination were partial mineral analyses including such pertinent parameters as total dissolved solids, hardness, calcium, magnesium, alkalinity (T & P), pH, iron and chlorides depending on the type of treatment process. The hardness and alkalinity determination are reported as $CaCO_3$ whereas the other chemical determination are reported as the element. The calcium and magnesium values would be multiplied by conversion factors of 2.5 and 4.11 respectively to convert to the $CaCO_3$ equivalent when determining hardness.

Field analyses including pH, hardness, calcium, magnesium, alkalinity and other parameters were performed to determine critical changes and appropriate times for sampling for more complete laboratory analyses. The field analyses were not made a part of the report.

Duplicates of approximately 10% of the samples were collected and analyzed by the laboratory to determine precision and accuracy of the analytical work. Some duplicates of samples were submitted to the Radiochemistry and Nuclear Engineering Facility of the Environmental Protection Agency in Cincinnati, Ohio.

SECTION 6

RADIOACTIVITY STUDIES IN IOWA WATER SUPPLIES

A long series of studies were begun in the State of Illinois by the Argonne National Laboratory[1] with the discovery in 1948 of high natural radioactivity in the drinking water of the adjoining municipal water supplies. The radioactivity was identified as resulting from radium-226 and other studies defined the boundaries of the geographic region in Illinois in which the high radium waters were present, the number of people involved and such metabolic factors as the relative contribution of both food and water to the whole body radium content of exposed individuals. The studies show that surface waters had mean radium-226 concentrations of 0.10 pCi/l whereas the mean radium-226 concentration of well water from the deep sandstone (Cambrian and Ordovician rocks) varied from less than 1 pCi/l to over 25 pCi/l with a mean concentration of 6.0 pCi/l. They concluded that the high radium water was associated primarily with water from the St. Peter Sandstone.

The Iowa State Hygienic Laboratory began very limited sampling and analysis of Iowa municipal ground water supplies for radioactive isotopes in the 1950's. The water supplies sampled during this period were primarily from the Jordan and St. Peter sandstones in southeast Iowa. Morris and Klinsky of the Laboratory[2] reported results of studies of radium-226 levels in eight water supplies and on the efficiency of zeolite water softeners in the removal of radium-226.

A memorandum from Ball[3] of the Iowa State Hygienic Laboratory in 1964 summarized the Midwest Environmental Health Study results of radium-226 analyses on a limited number of Iowa public water supplies as follows:

Total towns sampled	241
Towns with radium in raw water (0.5 pCi/l)	151
Towns with radium in finished water	
0.5 - 20 pCi/l	118
0.5 - 3.0 pCi/l	74
3.0 pCi/l	44
5.0 pCi/l	19
Towns removing radium during softening	33

Table 3, from the Midwest Study, lists the number of Iowa public water supplies with the radium-226 range and populations served.

TABLE 3

Radium Levels - Iowa Public Water Supplies - Finished Waters

Range-pCi/1	No. of Supplies	Population
0.26-0.49	123	581,269
0.50-0.99	22	48,359
1.00-1.99	34	88,426
2.0 -2.99	18	93,989
3.0 -3.99	17	118,089
4.0 -4.99	8	43,240
5.0 -5.99	5	3,859
6.0 -6.99	6	10,752
7.0 -7.99	1	4,952
8.0 -9.99	1	906
10.0-14.99	5	5,570
15.0-19.99	1	1,045
20	0	0
Total	241	1,000,456

The reporting of the elevated radium-226 concentration in Illinois and Iowa[4] well water supplies along with studies documenting cases in which relatively high levels of radium-226 deposited in the human skeleton produced malignant neoplasms (bone cancer) pointed out the epidemiological potential for dose-effect studies. In 1962, the Division of Radiological Health of the Public Health Service, in cooperation with the Argonne National Laboratory's Division of Radiological Physics and the State Health Departments of Illinois and Iowa, initiated the Midwest Environmental Health Study[5] to conduct an epidemiological investigation of human populations exposed to elevated levels of radium-226 in drinking water. The Iowa State Hygienic Laboratory performed the radiological analyses and compiled the data acquired over a period of two years by the joint project.

In 1962, the Public Health Service Drinking Water Standards[6] established a radium-226 concentration standard of 3 pCi/l. It had been shown that long term ingestion of water containing 3 or more pCi radium-226 per liter could result in a radium-226 total body burden at least twice that found in the population exposed to lower levels.

One epidemiological approach[7] following the midwest sampling and analysis program was to compare a population of almost 1,000,000 people in 111 communities, 72 in Illinois and 39 in Iowa, having elevated radium-226 levels above 3 pCi/l with a population with known exposure. Based on a retrospective analysis of data from death certificates this population group exhibited an adjusted bone neoplasm mortality rate of 1.41 death per 100,000 compared with a rate of 1.14 in a control population. The study concluded that confirmation and refutation of the finding will require a prospective analytic epidemiological study. No further studies were carried out.

A second study[8] following the well sampling program was to determine whether deciduous teeth are valid indications of long term low level ingestion of environmental radium-226. Pools of deciduous teeth from 35 Illinois and Iowa communities were analyzed and the correlation between radium-226 levels in water and deciduous teeth was found to be direct and apparently linear.

During 1969, the Iowa State Hygienic Laboratory, with funds provided by the Iowa State Department of Health, began a program which included radiological analyses on all samples collected for complete mineral-trace metals analyses. The State Department of Health funding of this analytical program was discontinued during 1972 but the State Hygienic Laboratory has continued the program to the extent possible with their existing program budget.

Sampling of all Iowa public water supplies and compilation of all existing radiological data is still not complete in 1974, but recent data indicates that of 567 public supplies sampled, 120 supplies exceeded the existing radium-226 standards of 3 pCi/l as contained in the 1962 Public Health Service Drinking Water Standards. The same data indicates that an additional 144 public supplies had radium-226 values ranging between 0.5 and 2.9 pCi/l or a total of 224 supplies out of 567 municipalities exceeding the 0.5 pCi/l value. The State of Iowa has over 800 public water supplies but it is felt that the radiological sampling at this time includes a majority of the high radium-226 content waters since an effort has been made in the past to include the deep well supplies with a potential for a high radium-226 content.

SECTION 7

WATER MINERALIZATION AND HEALTH

Some suggestive, although not conclusive, evidence[9] has been presented that indicates soft water or a low total dissolved solids water may not be as wholesome as hard or mineralized water. Whether this effect, if true, is related to calcium and magnesium, other trace elements in mineralized water or to the corrosiveness of soft water leaching some toxicant from water piping, is not known at this time.

Winton and McCabe[10] indicated a review of research on the relations of heart disease to soft water during the past decade or more uncovered sufficient correlation to suggest more definitive studies need to be undertaken to resolve the question. In recent years, coronary heart disease (CHD) has accounted for about 29 percent of all deaths in the United States and continues to rank as the nation's leading killer. The following discussion abstracts some of the review of the past research.

The correlation between the water constituents and cardiovascular disease (CVD) began in 1957 when a Japanese agricultural chemist[11] showed data linking acidity in river water with Japan's leading cause of death, cerebral hemorrhage. Areas of Japan with more acid rivers had higher mortality from this disease. At about the same time American investigators were directing attention to the striking unequal geographical distribution of the United States leading cause of death, CHD. States with low CHD were in the hard water areas of the western plains and some areas of mid-south and the high rate areas were predominantly along the east, west, and gulf coasts. Correlations using state mortality data indicated that calcium and magnesium were significantly and inversely correlated with CHD death rates. Studies were also published[13] regarding similar correlation in England, Sweden, the Netherlands, New York City, and counties in Oklahoma.

If there is a water factor influencing CHD or other cardiovascular disease, it should be possible to demonstrate at what step in the development of the disease it is operating. An international study found no correlation between soft water and the degree of deposition and narrowing of the coronary arteries. It has been well publicized that people with high blood cholesterol and other lipids are more prone to develop CHD. One study was able to decrease blood cholesterol and other lipids in men and women by doubling the calcium intake. A similar study found no remarkable difference in cholesterol when comparing men from hard water Omaha with a group from soft water Winston-Salem. However, the extra calcium received from the hard water was only a fraction of that received in the previous study. Another study indicated magnesium protects against lipid deposits in rats. A recent Canadiam study[13] indicates that magnesium is the element that is most probably responsible for associations between cardiovascular mortality and water hardness.

Studies[14] have suggested that corrosive soft water leaches cadmium from galvanized pipes and that perhaps cadmium is the real factor. Cadmium has been demonstrated as a causative factor in high blood pressure which affects the course of CHD and CVD. Another theory has been proposed that increased copper intake from copper water pipe may augment lipid deposition in arteries.

Another problem that has cast some doubt on the wisdom of softening is related to sodium. The increasing awareness of the health hazard of sodium in the diet has indicated that sodium cycle ion exchange and the use of soda ash for the removal of non-carbonate hardness must be viewed with caution.

In 1963, the Heart Disease Program[15] of the Public Health Service undertook a national survey of drinking water for sodium content. The basis of concern with sodium in drinking water is the treatment of patients with congestive heart failure. The greatest problem of therapy is edema associated with the disease. This edema, an excessive accumulation of fluid in the tissues, is closely related to excessive retention of sodium by the kidney. Dietary restriction of sodium is considered the basic diet therapy along with a high intake of fluid (3.5 liters water daily) to promote diuresis. Sodium may also be implicated in hypertension and certain kidney and liver diseases.

The American Heart Association[16] has defined a normal sodium intake of 3000 to 5000 mg/day compared with a severe restriction of only 200-500 mg for treatment of some cases of congestive heart failure. An extremely rigid selection of food is required and the sodium content of the water supply must also be considered. Some zeolite (ion exchange) softened water where sodium replaces the calcium and magnesium may provide two or three times more sodium than is allowed from food on a severely restricted diet.

SECTION 8

HYDROGEOLOGY

GENERAL

The geologic framework of Iowa's ground-water reservoir [17] is summarized in table 4 and figures 2 and 3. The bottom of the reservoir is the Precambrian crystalline complex, which occurs at a depth of about 5,200 feet in southwestern Iowa and rises to the surface in extreme northwestern Iowa and to within 800 feet of the surface in northeastern Iowa. Overlying this complex is a succession of consolidated sedimentary strata of Paleozoic age that are dominantly sandstones and dolomites in the lower part, and shales, dolomites, and limestones in the upper part. These strata have been downwarped into a broad trough, known as the Iowa Basin (Figure 4). The surface of the dipping Paleozoic strata was bevelled by erosion, thus exposing older Paleozoic strata in the northeastern and northwestern parts of the state and forming the extensive recharge areas of the Paleozoic aquifers in northeastern Iowa and southern Minnesota. The deep, highly productive artesian aquifers in Iowa are a considerable distance from these recharge sources.

The six principal water-yielding rock units in the Iowa reservoir are the surficial deposits, the Dakota Sandstone of Cretacous age, limestones and dolomites of Mississipian age, limestones and dolomites of Silurian and Devonian age, the Cambrian and Ordovician sandstones and dolomites, and the Dresbach sandstones of Cambrian age (Table 4). The most consistently productive units are the Cambrian and Ordovician sandstones and dolomites.

Dakota Sandstone Aquifer

Strata of Cretaceous age, principally the Dakota Sandstone (Table 4), comprise the chief bedrock aquifer in northwestern Iowa and less extensively in western and southwestern Iowa. These rocks are present across most of the northwestern part of the state as far east as Kossuth, Wright, Webster, Greene, and Guthrie Counties, and as irregular remnants as far south as Montgomery and Page counties (Figure 4). This aquifer covers about 20 percent of the state with dissolved solids concentration of less than 500 mg/l over less than 5 percent of the state and dissolved solids content of less than 1,000 mg/l over about 12 percent of the state.

Maximum thickness of the full Cretaceous System is somewhat more than 400 feet in central Sioux and Osceola counties, from where it thins northwestward and southeastward. The depth to the Dakota Sandstone varies considerably. Generally, in the northwestern counties it is

Figure 2

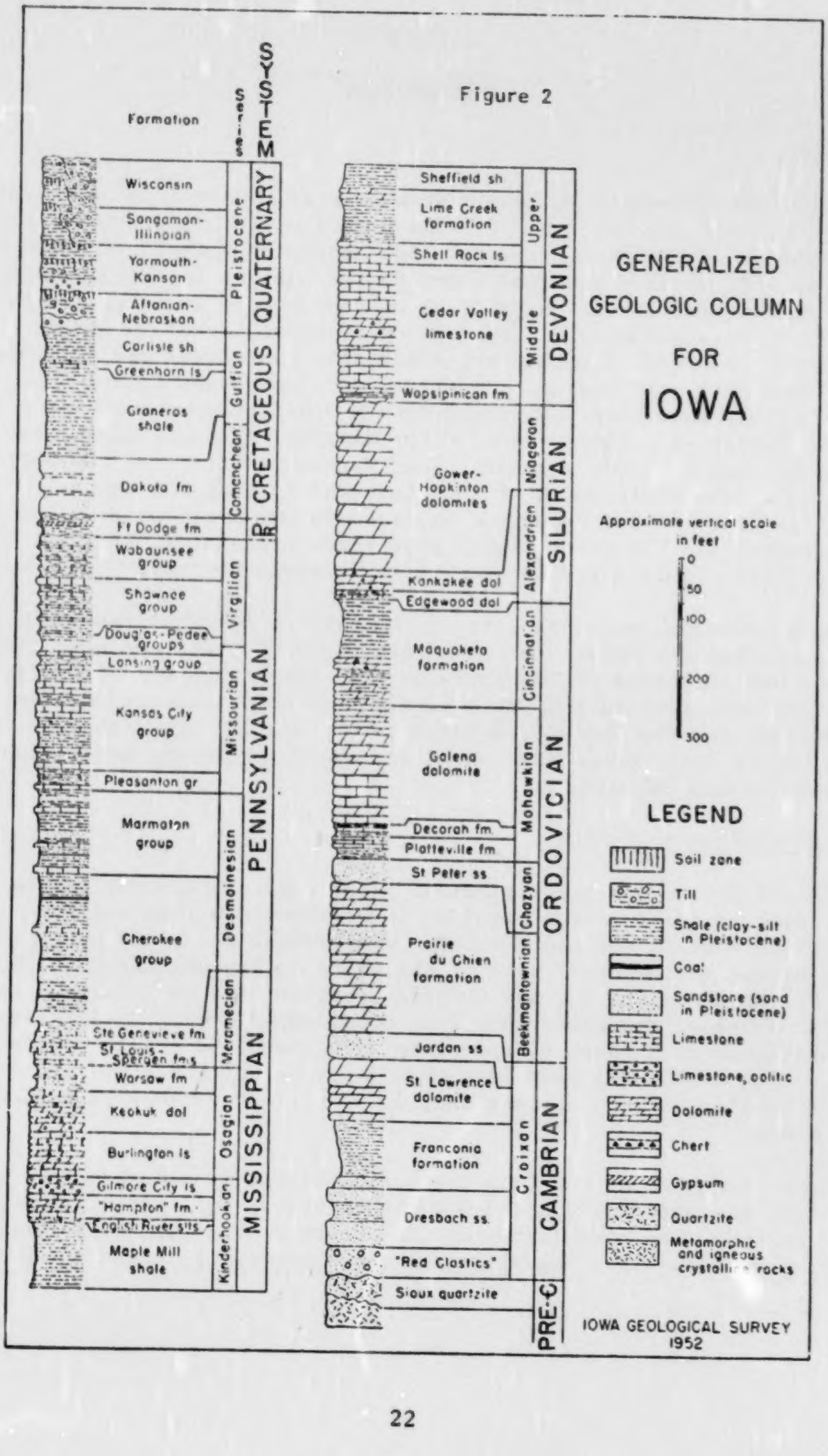

GENERALIZED GEOLOGIC COLUMN FOR IOWA
Formation
Series
SYSTEM
Wisconsin
Sangamon-Illinoian
Yarmouth-Kansan
Aftonian-Nebraskan
Pleistocene
QUATERNARY
Carlisle sh
Greenhorn ls
Graneros shale
Dakota fm
Gulfian
Comanchean
CRETACEOUS
Ft Dodge fm
P.
Wabaunsee group
Shawnee group
Douglas-Pedee groups
Virgilian
Lansing group
Kansas City group
Pleasanton gr
Missourian
Marmaton group
Cherokee group
Desmoinesian
PENNSYLVANIAN
Ste Genevieve fm
St Louis-Spergen fms
Meramecian
Warsaw fm
Keokuk dol
Burlington ls
Osagian
Gilmore City ls
"Hampton" fm
English River slts
Maple Mill shale
Kinderhookian
MISSISSIPPIAN
Sheffield sh
Lime Creek formation
Shell Rock ls
Upper
Cedar Valley limestone
Wapsipinicon fm
Middle
DEVONIAN
Gower-Hopkinton dolomites
Niagaran
Kankakee dol
Edgewood dol
Alexandrian
SILURIAN
Maquoketa formation
Cincinnatian
Galena dolomite
Decorah fm.
Platteville fm
Mohawkian
St Peter ss
Chazyan
Prairie du Chien formation
Jordan ss
Beekmantownian
ORDOVICIAN
St Lawrence dolomite
Franconia formation
Dresbach ss.
Croixan
CAMBRIAN
"Red Clastics"
Sioux quartzite
PRE-C
Approximate vertical scale in feet
0
50
100
200
300
LEGEND
Soil zone
Till
Shale (clay-silt in Pleistocene)
Coal
Sandstone (sand in Pleistocene)
Limestone
Limestone, oolitic
Dolomite
Chert
Gypsum
Quartzite
Metamorphic and igneous crystalline rocks
IOWA GEOLOGICAL SURVEY 1952

Figure 3

Generalized Hydrogeolic Section of Iowa

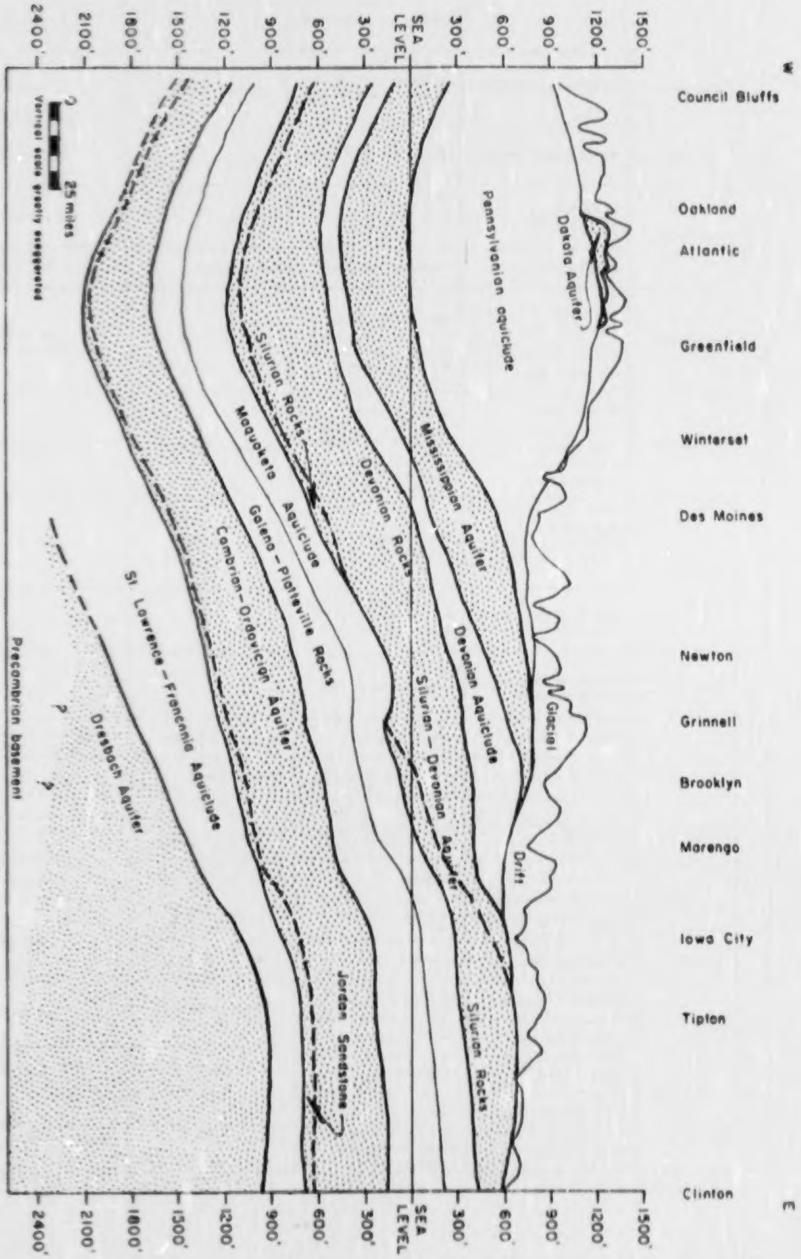

W
E
Council Bluffs
Oakland
Atlantic
Greenfield
Winterset
Des Moines
Newton
Grinnell
Brooklyn
Marengo
Iowa City
Tipton
Clinton
1500'
1200'
900'
600'
300'
SEA LEVEL
300'
600'
900'
1200'
1500'
1800'
2100'
2400'
Dakota Aquifer
Pennsylvanian aquiclude
Mississippian Aquifer
Devonian Rocks
Silurian Rocks
Maquoketa Aquiclude
Galena – Platteville Rocks
Cambrian-Ordovician Aquifer
St. Lawrence – Franconia Aquiclude
Dresbach Aquifer
Precambrian basement
Glacial
Drift
Devonian Aquiclude
Silurian – Devonian Aquifer
Silurian Rocks
Jordan Sandstone
?
?
0
25 miles
Vertical scale greatly exaggerated

TABLE 4

Geologic and Hydrogeolic Units in Iowa

AGE		ROCK UNIT	DESCRIPTION	HYDROGEOLOGIC UNIT	WATER-BEARING CHARACTERISTICS
Cenozoic	Quaternary	Alluvium	Sand, gravel, silt and clay	Surficial aquifer	Fair to large yields
		Glacial drift (undifferentiated)	Predominantly till containing scattered irregular bodies of sand and gravel		Low yields
		Buried channel deposits	Sand, gravel, silt and clay		Small to large yields
Mesozoic	Cretaceous	Carlile Formation Graneros Formation	Shale	Aquiclude	Does not yield water
		Dakota Group	Sandstone and shale	Dakota aquifer	High to fair yields
Paleozoic	Pennsylvanian	Virgil Series Missouri Series	Shale and limestone	Aquiclude	Low yields only from limestone and sandstone
		Des Moines Series	Shale; sandstones, mostly thin		
	Mississippian	Meramec Series	Limestone, sandy	Mississippian aquifer	Fair to low yields
		Osage Series	Limestone and dolomite, cherty		
		Kinderhook Series	Limestone, oolitic, and dolomite, cherty		
	Devonian	Maple Mill Shale Sheffield Formation Lime Creek Formation	Shale; limestone in lower part	Devonian aquiclude	Does not yield water
		Cedar Valley Limestone Wapsipinicon Formation	Limestone and dolomite; contains evaporites in southern half of Iowa	Silurian-Devonian aquifer	High to fair yields
	Silurian	Niagaran Series Alexandrian Series	Dolomite, locally cherty		
	Ordovician	Maquoketa Formation	Shale and dolomite	Maquoketa aquiclude	Does not yield water, except locally in northwest Iowa
		Galena Formation	Limestone and dolomite	Minor aquifer	Low yields
		Decorah Formation Platteville Formation	Limestone and thin shales, includes sandstone in SE Iowa	Aquiclude	Generally does not yield water, fair yields locally in southeast Iowa
		St Peter Sandstone	Sandstone	Cambrian-Ordovician aquifer	Fair yields
		Prairie du Chien Formation	Dolomite, sandy and cherty		High yields
	Cambrian	Jordan Sandstone	Sandstone		
		St Lawrence Formation	Dolomite	Aquiclude (wedges out in northwest Iowa)	Does not yield water
		Franconia Sandstone	Sandstone and shale		
		Dresbach Group	Sandstone	Dresbach aquifer	High to low yields
Precambrian		Sioux Quartzite	Quartzite	Base of ground-water reservoir	Not known to yield water except at Manson cryptovolcanic area
		Undifferentiated	Coarse sandstones, crystalline rocks		

1/ Stratigraphic nomenclature does not conform to U S Geological Survey usage

Source: Water Resources of Iowa - 1970

necessary to drill between 250 and 600 feet to penetrate the Dakota aquifer, whereas in the eastern areas the Dakota usually can be reached at between 100 and 350 feet.

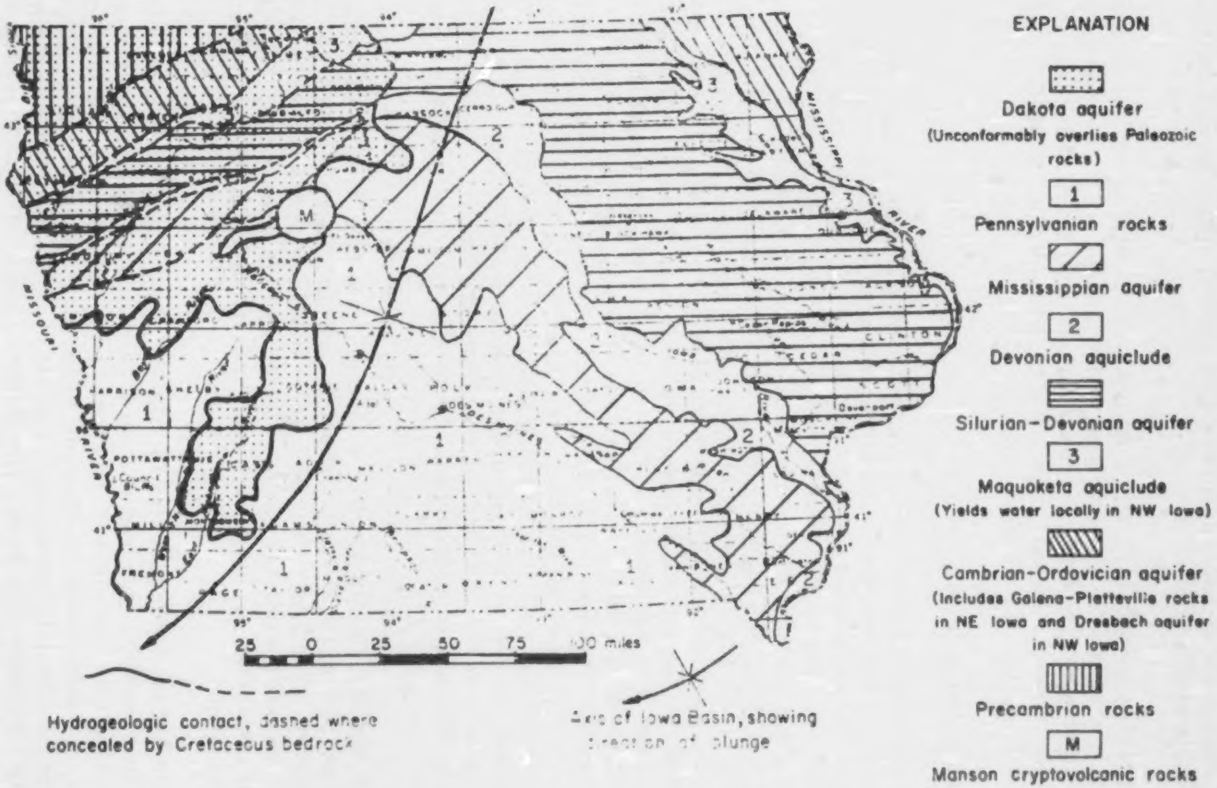
The Dakota aquifer generally can be counted on to produce sufficient water for all rural and many municipal requirements. Even where the aquifer is only moderately thick, many wells have been developed to yield 50 to 100 gpm. Some municipal wells in Osceola, O'Brien, Sioux and Cherokee Counties have been tested at 350 and 750 gpm.

Cambrian-Ordovician Aquifer

The Cambrian-Ordovician aquifer is widespread throughout the State of Iowa (Figure 4). The aquifer consists of three water bearing formations, the St. Peter Sandstone and Prairie du Chien Formation of the Ordovician Age and the Jordan Sandstone of the Cambrian Age (Table 4). The St. Peter Sandstone formation rarely reaches a thickness of over 50 feet. It is capable of producing wells yielding 50 gpm but is usually cased off when drilling wells to this aquifer to prevent caving or to shut off poorer quality water. The underlying Prairie du Chien Formation is several hundred feet thick in eastern and southern Iowa but it thins out towards the northwest. This formation is believed to yield significant amounts of water to wells penetrating the Cambrian-Ordovician aquifer; however, its performance is generally overshadowed by the underlying Jordan Sandstone. The Prairie du Chien is the principle water producing unit for some wells in south central Iowa. The Jordan Sandstone is the principal water producing unit and is penetrated by practically all wells drilled to the Cambrian-Ordovician aquifers. This sandstone thickness ranges from 75 to 125 feet in southwestern Iowa.

The dissolved solids concentration in water from the Jordan Sandstone is often less than 300 mg/l in the northeast and increases toward the west and south. Water with less than 500 mg/l of dissolved solids is found in the Jordan aquifer over more than 20 percent of the state, less than 1,000 mg/l in more than 35 percent, and less than 1,500 mg/l in over 60 percent of the state.

The Cambian-Ordovician aquifer (principally the Jordan Sandstone) consistently yields several hundred to more than one thousand gpm of water from individual wells throughout the eastern three-fourths of the state. The aquifer is present beneath younger Paleozoic rocks at progressively greater depths to the southwest and southeast. The depth to the top of the aquifer in southwestern Iowa, the deepest part of the Iowa Basin, is about 3,200 feet (Figure 3). The total thickness of the water bearing unit ranges from 0 to 600 feet in eastern Iowa and from 0 to 400 feet in the western part of the state; the average thickness throughout its subsurface extent is generally between 400 to 500 feet.


EXPLANATION
Dakota aquifer
(Unconformably overlies Paleozoic rocks)
1
Pennsylvanian rocks
Mississippian aquifer
2
Devonian aquiclude
Silurian-Devonian aquifer
3
Maquoketa aquiclude
(Yields water locally in NW Iowa)
Cambrian-Ordovician aquifer
(Includes Galena-Platteville rocks in NE Iowa and Dresbach aquifer in NW Iowa)
Precambrian rocks
M
Manson cryptovolcanic rocks
Hydrogeologic contact, dashed where concealed by Cretaceous bedrock
Axis of Iowa Basin, showing direction of plunge
25 0 25 50 75 100 miles
MISSISSIPPI RIVER
MISSOURI RIVER
CLINTON
CEDAR
SCOTT
Davenport
Des Moines
POTTAWATTAMIE
FREMONT
HARRISON
SHELBY
POLK

Hydrogeologic Map of Iowa

Figure 4

The aquifer is utilized extensively by municipalities and industries in the eastern three-fourths of the state. Many small communities in central and southern Iowa also utilize the aquifer because the overlying rocks do not yield enough water or the water is highly mineralized. Yields of up to 1,000 gpm are obtainable in most of the northeastern one-half of the state. Limited well data indicate that yields of only 100 to 300 gpm are available in much of the southwestern quarter of the state.

Significant lowering of the aquifer's pressure head has occurred at a number of localities where large amounts of water are pumped from the aquifer. Loss of pressure head in the vicinity of wells pumping from the aquifer have been recorded at Ottumwa (100 feet in 70 years), Grinnell (100 feet in 80 years), Des Moines area (50 feet in one year) and a number of other smaller communities in southeastern Iowa.

PROJECT STUDY WELL INFORMATION

Information obtained from the Iowa Geological Survey on the wells sampled during the project study summarizes the well depth, casing data and principal water producing zones. All municipalities utilize the Jordan sandstone as the principal water producing formation with the exception of Holstein which obtains waters from the shallower Dakota sandstone formation.

The Adair town well, drilled in 1968 by Thorpe Well Company to a depth of 2700 feet, is cased from surface to 1183' with 8" casing and from 1180-2475' with 5" casing. The casing is cemented from top to bottom and extends 80' below the top of the Prairie du Chien. The principal producing zone is the Jordan sandstone and some water may be obtained from the lower Prairie du Chien formation.

The Eldon town well was drilled in 1961 by Thorpe Well Company to a depth of 1901 feet. Construction consists of 12" casing to 260', 10" casing from 260' to 775' and 8" casing from 775' to 1590', about 359' below the top of the Prairie du Chien. The entire length of casing is grouted with cement. The principal source is the Jordan with some water entering from the lower Prairie du Chien and from the St. Lawrence Dolomite formation.

The Estherville city well was drilled in 1965 by Layne-Western Company to a depth of 750 feet into the St. Lawrence. It was cased with 462' of 16" casing 0-462' into top of the St. Peter Sandstone and is grouted with cement to 462'. The source of water is the interval from the St. Peter Sandstone through the St. Lawrence Dolomite.

The Greenfield town well was drilled in 1929 by Layne-Bowler and rebuilt by Thorpe Well Company in 1967. The depth is 3467' and reportedly cased from surface to 3100'. The producing source apparently is the Prairie du Chien-Jordan-upper St. Lawrence sequence.

The Grinnell city No. 6 well was drilled in 1954-5 by Thorpe Well Company. The original depth was 2970' into Mt. Simon Sandstone but was plugged back to 2550' on top of Franconia siltstone and dolomite. The casing record shows 700' of 19" casing 0-700', cemented in; 1325' of 12" casing 675-2000', cemented in; and 710' of 10" casing 1975'-2685'. After the well was plugged back to 2550' the casing was perforated opposite the Jordan and St. Lawrence Formations which are the producing zones. Three other similar wells are drilled to depths of 2250' to 2550'.

The Holstein well No. 1 was drilled 1937 by Thorpe Well Company to a depth of 644' with 95' of well screen. Only a partial log is available but a log of an adjacent well gives the Dakota Sandstone as the principal water bearing formation at 610'.

The Stuart town well was drilled in 1962 by Thorpe Well Company to a depth of 2801 feet into St. Lawrence Dolomite. Construction consists of 260' of 22" casing 0-260'; 832' of 14" casing 0-832'; and 8" casing set at 2375' about 41' into the upper part of the Prairie du Chien, and grouted in with cement back into the 14" casing. The Jordan is the principal producing zone although some water probably is derived from the Prairie du Chien and perhaps the St. Lawrence formations.

The Webster City No. 5 city well was drilled in 1954 by Thorpe Well Company to a depth of 2005' into St. Lawrence Dolomite. The casing record is incomplete, but 12" casing reportedly extends to 1446' into the St. Peter or to 1500' into the Upper Prairie du Chien. There is no report on whether the casing was cemented in. Probably the Jordan is the main producing zone with some water coming in from the Prairie du Chien and St. Lawrence formations. A second well of identical depth and similar construction is also in use.

The West Des Moines city well was drilled in 1967 by L. F. Winslow to a depth of 2460' into St. Lawrence Dolomite. The casing record shows 48' of 30" casing, 0-48; 412' of 16" casing, 0-412; and 1613' of 10" casing from 412' to 2025', about 62' into upper part of the Prairie du Chien Dolomite. The casing reportedly is cemented from top to bottom. Water is obtained from the Prairie du Chien and Jordan formations. A second well with similar characteristics is also in use.

SECTION 9

WATER TREATMENT PLANT WASTES

REVERSE OSMOSIS REJECT WATER DISPOSAL

Normally iron, calcium, and other ions removed with the reject water remain in solution and normally large amounts of pretreatment chemicals are not added in the process. If the clear reject water from the permeators discharge to join the effluent from the municipal sewer system the total would yield an effluent similar to the untreated hard water. The reject water may contain up to three times the total solids present in the raw well water.

SPENT BRINE DISPOSAL

One of the problems created by sodium ion-exchange softening is the disposal of spent brine from the regeneration cycle in view of increasing water pollution control requirements. This disposal problem becomes more sensitive when considering the concentration of radioactive isotopes. The backwash water preceeding the regeneration cycle may contain small amounts of iron or organic material. The waste products from the brine and rinse cycle are composed principally of the chlorides of calcium and magnesium and the excess salt necessary for regeneration since an equivalent amount of hardness is not removed for the amount of salt used.

The total wastewater may vary from 2 to 10% of the amount of water softened. The wastewater will contain chloride ions (principally sodium, calcium and magnesium compounds) proportional to the amount of salt used in regeneration. This will usually be .4 - .6 lbs of salt per 1000 grains of hardness removed. The amount of salt to be disposed of in the wastewater may be approximated by the formula $C = 35SH$, in which C represents the chloride ion expressed in pound per million gallons, S is the salt, in pounds per 1000 grains of hardness removed and H is the reduction of hardness in mg/l of calcium carbonate. The total solids in a composite sample of a typical spent brine may vary from an average concentrations of 50,000 to 100,000 mg/l to a maximum concentration of 70,000 to 200,000 mg/l.

Discharge of brine wastes onto pasture land can create "slugs" of high total dissolved solids water detrimental to livestock watering uses. Likewise discharge into a watercourse may cause damage to fish life. Discharge into storage ponds may infiltrate into ground water supplies and cause long term damage. Waste brines in a sanitary sewer system may seriously upset the biological processes in sewage treatment plants especially if "slugs" of highly concentrated brine flow directly to the plant. In the State of Iowa which has a large number of ion exchange softening plants there have been few reported detrimental effects from the discharge of brine waste even where such discharge is into an intermittent water course through pasture land.

Several alternate disposal methods have been proposed and discussed. Paul D. Haney[24] in a report given as a part of an A.W.W.A. Committee Report suggested several disposal methods.

1. Evaporation ponds.

Except under very unusual conditions, evaporation does not appear to offer satisfactory means of disposal of ion exchange plant wastes. Studies in Kansas indicated evaporation of oil field brine was less than the rainfall. Evaporation data for fresh waters are not applicable to brines because of the lowering of the vapor pressure by the dissolved salts. Disposal of residual salts would be a problem. Where soils are porous, watertight ponds are expensive to construct and experience indicates many are seepage ponds.

2. Uncontrolled Dilution.

Discharge of the waste brine into a watercourse is the most common and offers the most economical means of disposal, provided adequate dilution is available. Stream flow must be sufficient to provide dilution to a level to protect fish life and other downstream water uses.

3. Controlled Dilution

Disposal by controlled dilution requires short term or long term storage with discharge into a stream to keep salt content lower than the maximum allowable water quality standard.

4. Brine Disposal Wells

Brine wells may provide a means of disposing of spent brine but it may be feasible only in the oil well field areas. Brine treatment may also be necessary for conditioning before injection into the formations receiving the brine.

5. Brine Reclamation

Only a portion of the partially spent brine could be used for subsequent regeneration. In general the first one-third of the spent brine from the brine rinse would contain 80% of the hardness. These calcium and magnesium ions interfere with the regneration and decrease the exchange capacity. The middle one-third of brine rinse is high in sodium and might be used in subsequent regeneration to backwash the softener or used initially in the regeneration followed by sufficient fresh brine to attain the desired capacity. The principle of mass action requires an excess of salt for regeneration. Some reduced salt costs and a reduction in the amount of spent brine requiring disposal are benefits for reclamation which must be weighed against cost of additional piping and spent brine holding tanks.

LIME-SODA ASH SOFTENING WASTE DISPOSAL

Lime-Soda Ash Sludge

Discharge of water treatment plant wastes into a watercourse, historically the most widely used method of such disposal, may soon be eliminated as an acceptable practice. Several years ago, a vast majority of plants disposed of their sludges in this manner but recent Federal and State regulations now prohibit the discharge of waste sludges to streams.

The sludge produced during the softening process consists principally of calcium carbonate but contains varying amounts of magnesium hydroxide, aluminum hydroxide, or other coagulants. The type of water treated and the degree of softening practiced will determine the amount of these constituents. Spent lime sludge may be concentrated up to 10 percent solids in clarifier basins.

Given a prohibition against releasing sludge to streams, there are four basic alternatives. They are:

1. Lagooning
2. Disposal on land
3. Release to the sewer
4. Reclamation and reuse of chemicals

When direct discharge into a water course is not used, lagooning ranks high in popularity particularly for lime sludges. Lagoons are most commonly used with two or more basins operated alternately so that the excess moisture may be skimmed off or permitted to evaporate. When sufficiently dry to be moved, the sludge may be used to raise the dikes, used for landfill, or as soil sweetner. It may be economically feasible to pump lime sludge several miles to inexpensive lagoon areas.

Dewatering by a variety of means and final disposal on land either in a landfill or for agricultural use is a growing method of lime sludge disposal. Dewatering can be accomplished by vacuum filters, belt filter presses, pressure filters and centrifuges. Studies in the State of Iowa indicate the vacuum filter may be the simplest and most economical method.

Discharge of sludges to sewers may cause some problems in clogging of flat sewers and affect sewage treatment plant operations. In some instances there has been improvement of sedimentation or in reduction of phosphates in sewage. The volume of spent lime solids is much greater than the amount of 0.2 pounds of sewage solids contributed per capita per day. Likewise, the calcium carbonate comprising a high percentage of the spent lime solids would increase the normal digester alkalinity many times which would stop biological activity of the anaerobic digester.

In one Iowa waste water treatment plant, spent lime solids were discharged to the waste water plant for one week. Pumping of the settled solids to an incinerator of the fluidized bed type caused the lime in the sludge to build up a thick coating on the sand particles resulting in clogging of the reactor and the discharge to the sewer was terminated.

Recalcination of softening plant sludges for recovery of lime is practiced in a very few large plants. As indicated by the 1972 AWWA Committee Report[25], "Disposal of Wastes from Water Treatment Plants", fluidized bed reactors are feasible for 20 ton capabilities while rotary kiln operations required 40 tons. Therefore, recalcination is feasible only in the larger plants. One Iowa recalcination installation serving a population of 25,000 was constructed in 1948 but has since been abandoned.

A unique disposal method which has just been initiated by the City of West Des Moines is pumping of the lime sludge to a nearby cement plant which utilizes the sludge and added moisture in the production of cement. Consideration is also being given to reconstituting the dried lagooned lime sludge and also utilizing this sludge in the cement manufacture.

Filter Backwash Water

Recovery of filter backwash water appears to be gaining in popularity and undoubtedly will become more common. When coagulation is used, the filter backwash water is retained in a wash water holding tank or backwash water clarifier and returned at about a 5 percent rate to the plant inlet ahead of any chemical additions. The procedure not only recovers all of the waste water, but may improve the coagulation or softening process by providing nuclei for floc formation.

SECTION 10

REVERSE OSMOSIS DESALTING

SECTION 10.1

PROCESS DESCRIPTION

When high hardness waters of different concentrations are separated by a semi-permeable membrane, water from the less concentrated side will migrate through the membrane to the more concentrated side in an attempt to equalize the concentrations. The semi-permeable membrane allows water, but not dissolved solids to pass through it. This physical chemical phenomenon is known as osmosis. During osmosis the volume of the more concentrated solution will increase with a resulting pressure increase. There is an effective pressure gradient across the membrane in the direction of flow of the water. This driving pressure for the flow of pure water is known as osmotic pressure. By putting sufficient hydraulic pressure on the more concentrated side, the osmotic pressure gradient can be overcome and an effective pressure gradient in the opposite direction can be imposed. This creates a flow of water in the direction opposite of normal osmosis, thus it is referred to as reverse osmosis[18]. See Figure 5.

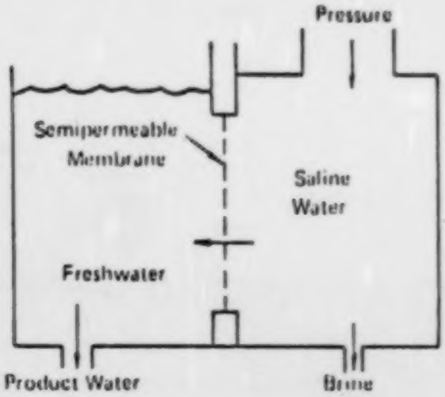


Figure 5
Basic RO Unit

In the reverse osmosis desalting process the high hardness water is pressurized and piped into a reverse osmosis unit where relatively pure water diffuses through the semi-permeable membrane and becomes the product water leaving a concentrated "reject" water. Characteristic of essentially all reverse osmosis membranes, rejection of divalent ions such as Ca, Mg and SO_4 is much greater than for the monovalent ions Na and Cl.

The DuPont Permasep Permeators used at Greenfield, Iowa utilize the hollow fiber concept. Membrane materials have been formed into hollow fibers which may measure from 25 to 250 microns in diameter (approximately 0.001 to 0.01 inch). These very small diameter fibers can withstand high pressures. Bundles of these fibers are sealed together at one end and then cut to open the fiber ends and placed in a pressure vessel. The pressurized feed water is on the outside of the hollow fibers. The water permeates through the hollow fiber wall and into the bore leaving most of the dissolved solids and other contaminants behind. Simultaneously the waste stream (reject) water flows from another port in the unit carrying out the high dissolved solids content. The hollow fiber reverse osmosis concept is illustrated in figures 6 and 7.

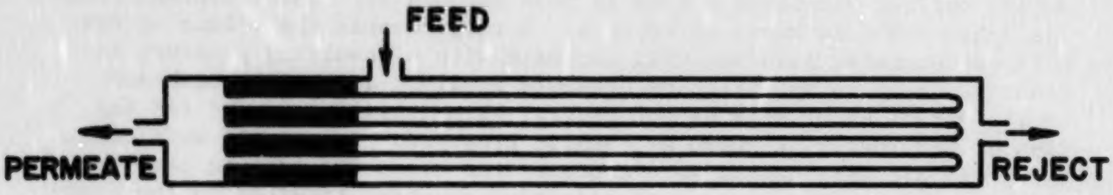
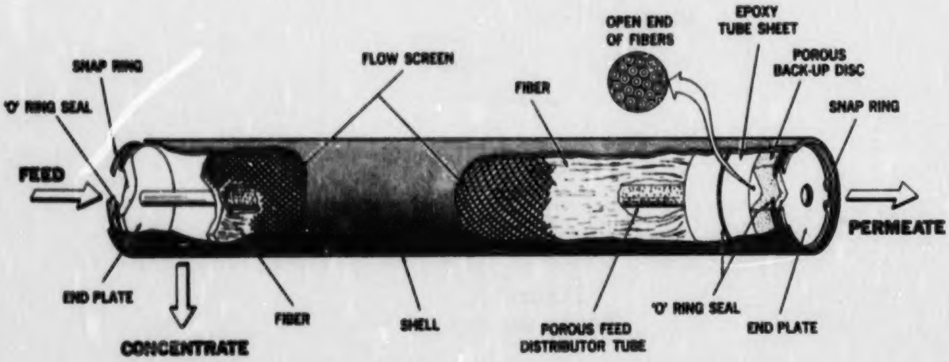

FEED
PERMEATE
REJECT

Figure 6
Schematic Diagram of Hollow Fiber
Reverse Osmosis Unit


SNAP RING
'O' RING SEAL
FEED
FLOW SCREEN
FIBER
OPEN END OF FIBERS
EPOXY TUBE SHEET
POROUS BACK-UP DISC
SNAP RING
PERMEATE
END PLATE
CONCENTRATE
FIBER
SHELL
POROUS FEED DISTRIBUTOR TUBE
'O' RING SEAL
END PLATE

CUTAWAY DRAWING OF PERMASEP® PERMEATOR

Figure 7

Pretreatment of the feed water is necessary to prevent fouling of the membranes by suspended solids, iron, manganese and precipitation of calcium carbonate and magnesium hydroxide.

Product water recovery, the amount of finished water obtained from the feed water, can be varied. Normal recovery ranges for municipal installations may be in the 70 to 90% range, usually limited by the waste stream (reject) water concentrations of certain ions which can become supersaturated and precipitate.

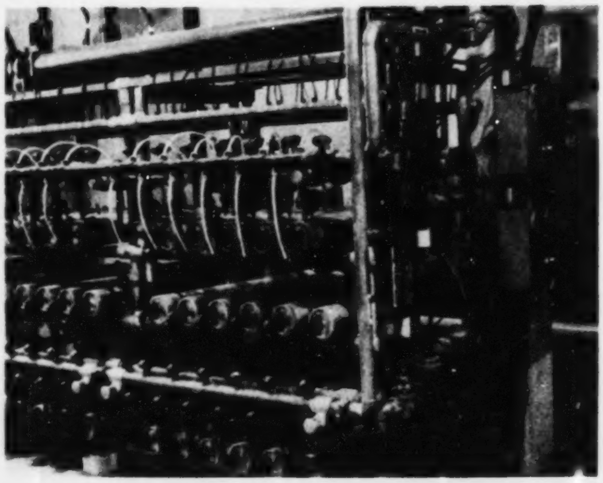
SECTION 10.2

GREENFIELD

BACKGROUND DATA

Greenfield is the County seat of Adair County and is located about 60 miles southwest of Des Moines. Greenfield is a typical small rural Iowa community, located in an agricultural area which is not heavily populated. The population of Adair County was 9,487 in 1970. The population of the county has been showing significant declines over the past four decades. The City of Greenfield had a 1970 population of 2,212 which was a slight drop from 2,243 in 1960.

The usual water supply for the town is an impoundment of surface water. The quality of this water is very good, with a total solids content of about 200 mg/l. But during periods of drought, the supply of good surface water decreases, and the town must supplement its supply with water from a 3,500 foot well that taps into the Jordan Aquifer. Unfortunately, the deepwell water is of a poor brackish quality, with a total solids (TS) content of more than 2,200 mg/l. In 1971 Greenfield installed a reverse osmosis desalting plant to treat this well water, thus becoming the first municipality owned reverse osmosis desalting plant in the nation. Figure 8 is a schematic diagram of both of Greenfield's water treatment facilities. Figure 9 indicates the arrangement of the reverse osmosis units within the plant.



Greenfield RO Plant
Figure 9

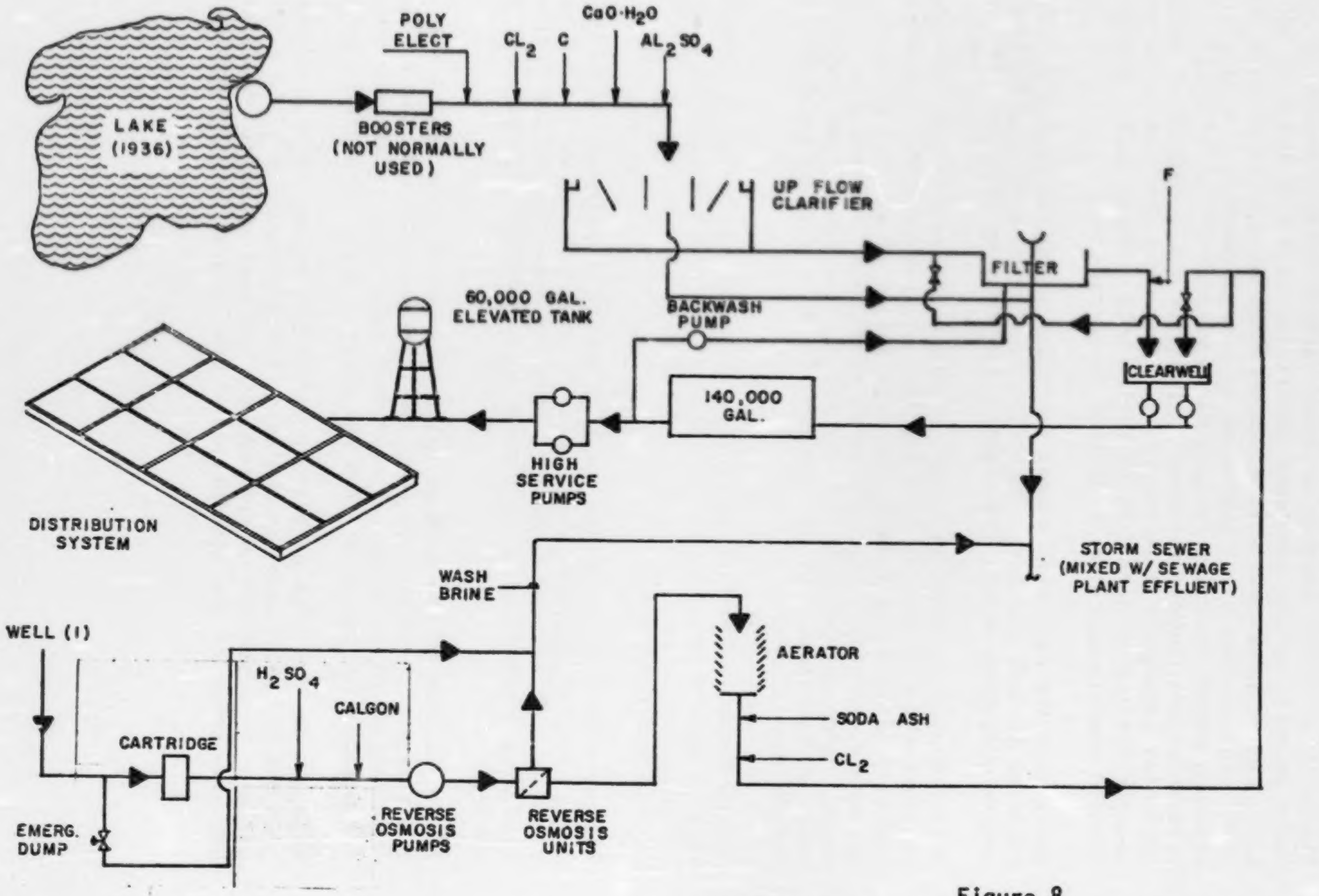

LAKE (1936)
BOOSTERS (NOT NORMALLY USED)
POLY ELECT
CL_2
C
$CaO \cdot H_2O$
AL_2SO_4
UP FLOW CLARIFIER
F
FILTER
BACKWASH PUMP
CLEARWELL
60,000 GAL. ELEVATED TANK
140,000 GAL.
HIGH SERVICE PUMPS
DISTRIBUTION SYSTEM
STORM SEWER (MIXED W/ SEWAGE PLANT EFFLUENT)
WASH BRINE
WELL (1)
H_2SO_4
CALGON
CARTRIDGE
AERATOR
SODA ASH
CL_2
EMERG. DUMP
REVERSE OSMOSIS PUMPS
REVERSE OSMOSIS UNITS

Figure 8
WATER SYSTEM SCHEMATIC - GREENFIELD

Reverse Osmosis Treatment Facilities

Figure 10 is a flow diagram of Greendfield's reverse osmosis plant[19]. These reverse osmosis treatment facilities have a capacity of 150,000 gpd. The equipment consists of three banks of reverse osmosis permeators. The equipment was installed in the basement of the City's existing water treatment facilities in a space 25' x 25' x 12'. The permeators are DuPont "Permasep" permeators which consist of aluminum cylinders (about 5½" diameter by 48" in length) which serve as pressure vessels housing about a million hollow nylon fibers each. Hollow fiber reverse osmosis units are described in section 9.1.

Water from the deep well enters the plant at 50 psi pressure. It is filtered through 10-micron Filterite depth-type cartridge filters which remove suspended solids that might cause fouling problems.

Sulfuric acid is added at a rate of about 160 mg/l to the raw feed water to lower the pH from 7.2 to 5.5. The acid converts the bicarbonate to carbon dioxide which reduces the possibility of precipitation of calcium carbonate. Further, there is about 1.6 mg/l of ferrous iron in the raw water. Iron is more likely to remain in solution at the lower pH and thus can be rejected by the permeator. No additional pretreatment to remove iron is used.

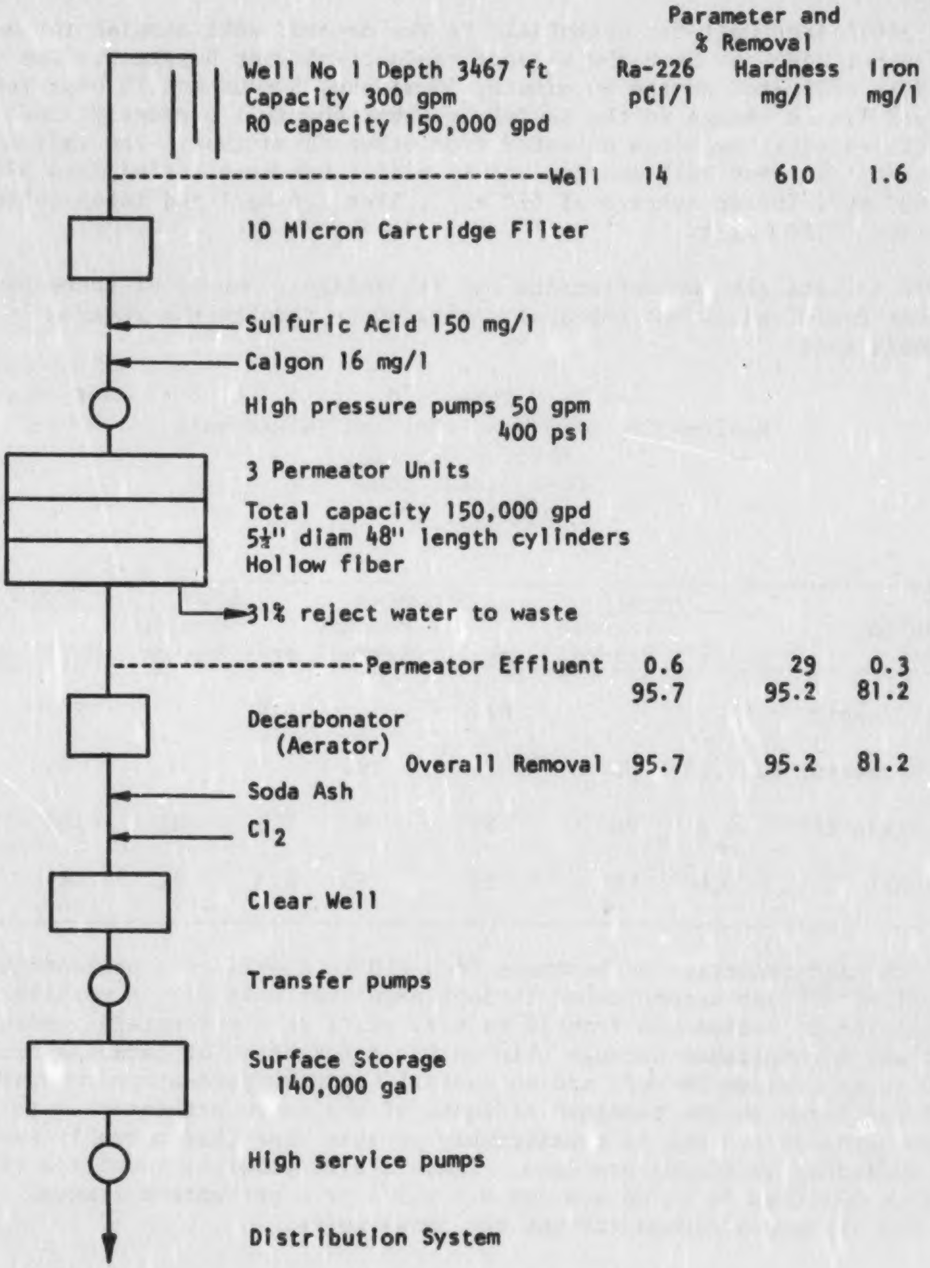
Sodium hexametaphosphate is added to the raw feed water at 16 mg/l before it enters the permeators. This sequesters the calcium, thereby inhibiting the precipitation of calcium sulfate; it also aids in iron precipitation control.

The pretreated water enters the high pressure (400 psi) Gould multistage centrifugal pumps which feed the permeators. By reverse osmosis, these permeators remove the most unwanted dissolved solids from the feed water, producing product water at a recovery rate of about 69 percent.

Post treatment of the product water consists of decarbonation by means of an aerator, addition of soda ash to raise the pH to the 7-8 range, and addition of chlorine. The product water then enters the clearwell for mixing with the water from the surface water treatment plant.

Reject water from the permeators discharges by way of a storm sewer to join the effluent from the municipal sewage system to yield a total effluent very similar to the one obtained when untreated brackish water was used prior to the acquisition of the reverse osmosis plant.

Figure 10
Flow Diagram
Greenfield, Iowa - Population 2,212
Reverse Osmosis Desalting Plant
August 8, 1974


Well No 1 Depth 3467 ft
Capacity 300 gpm
RO capacity 150,000 gpd
Well
10 Micron Cartridge Filter
Sulfuric Acid 150 mg/l
Calgon 16 mg/l
High pressure pumps 50 gpm
400 psi
3 Permeator Units
Total capacity 150,000 gpd
5½" diam 48" length cylinders
Hollow fiber
31% reject water to waste
Permeator Effluent
Decarbonator
(Aerator)
Overall Removal
Soda Ash
Cl_2
Clear Well
Transfer pumps
Surface Storage
140,000 gal
High service pumps
Distribution System

	Parameter and % Removal		
	Ra-226 pCi/l	Hardness mg/l	Iron mg/l
Well	14	610	1.6
Permeator Effluent	0.6 95.7	29 95.2	0.3 81.2
Overall Removal	95.7	95.2	81.2

Reverse Osmosis Performance

Table 5 is a tabulation of the radiological and chemical analyses performed on samples collected from the deep well and various stages in the reverse osmosis units. Additional mineral analyess are shown in Appendix A. Percent removals of radium-226, hardness and iron are also shown in figure 10.

The 3467' deep well for Greenfield is the deepest well sampled in the study but does not have the highest radioactivity or hardness. The samples collected at the 10 minute, 30 minute, 5 hour and 15 hour intervals showed little change in the radium or other chemical parameters indicating little vertical recharge of water from other formations. The radium-226 value on all four well samples was 14 pCi/l, hardness varied from 595 to 630 mg/l for an average of 610 mg/l, iron 1.6 mg/l and total solids averaged 2,160 mg/l.

Table 6 lists the concentrations and percentage removals of these pertinent radiological and chemical constituents through the reverse osmosis unit.

Table 6
Radium-226, Hardness, Iron and TS Removals
Reverse Osmosis
Greenfield, Iowa
August 8, 1974

	Ra-226		Hardness		Iron		Total Solids	
Sampling Point	pCi/l	Percent Removal	mg/l	Percent Removal	mg/l	Percent Removal	mg/l	Percent Removal
Well Supply	14		610		1.6		2160	
RO Permeator #1	0.35	97	4	99			99	95
RO Plant Eff	0.6	96	29	95	0.3	81	164	93
Overall	0.6	96	29	95	0.3	81	164	93

A very high reduction of hardness from 610 to 4 mg/l or a percentage removal of 99% was accomplished through permeator unit #1. A parallel reduction of radium-226 from 14 to 0.35 pCi/l or a percentage removal of 97% was accomplished through this unit. A reduction of hardness from 610 to an average 29 mg/l and an overall hardness percentage removal of 95% was found in the combined effluent of the three permeator units. This hardness removal is considerably greater than that normally used in municipal softening practice. Again a high parallel reduction of radium-226 from 14 to an average 0.6 pCi/l or a percentage removal of 96% was accomplished through the three units.

Table 5
Radiological and Chemical Analysis
Greenfield, Iowa Water Supply
August 8, 1974

Sampling Point	Gross Alpha pCi/l	Ra 226 pCi/l	Hard-ness mg/l	Total Solids mg/l	Alkalinity		pH	Iron		Ca mg/l	Mg mg/l	Na mg/l	Mn mg/l	Cl mg/l	SO_4 mg/l
					P mg/l	T mg/l		Total mg/l	Sol mg/l						
Well #1 3467' 10 min	25	14	595	2159	0	196	7.6			170	54				860
Well #1 3467' 30 min	23	14	600	2159	0	192	7.6			170	54				880
Well #1 3467' 5 hr	21	14	630	2150	0	190	7.8	1.6	1.6	160	54	440	0.01	395	870
Well #1 3467' 15 hr	30	14	595	2162	0	193	7.7			170	54				890
*RO Permeator #1 10 min	1.0	0.3	4	100	0	28	5.6			1.7	0.7				40
RO Permeator #1 5 hr	0.4	0.4	4	99	0	40	5.25			1.0	0.4				33
RO Plant Eff 30 min	0.9	0.7	26	172	0	35	5.15			6.4	2.4				84
RO Plant Eff Dup	1.3	0.6	22	162	0	41	5.4			5.4	2.1				70
RO Plant Eff 5 hr	Nil	0.5	40	159	0	44	5.9	0.3	0.3	6.7	2.3	55	0.01	40	50
RO Perm. #1 Reject 30 min	112	48	1850	6515	0	10	4.75			480	160				3000
RO Perm. #1 Reject 5 hr	86	38	1840	6470	0	46	5.8	4.1	4.1	480	160	1300	0.01	1200	2900
RO Perm. #3 Reject 30 min	69	56	2070	7307	0	1.0	4.15			550	180				3200
RO Perm. #3 Reject 5 hr	77	48	2070	7248	0	35	5.25			540	180				3000

*Reverse Osmosis

As shown in table 5 two samples for radiological and chemical analyses were collected from the reverse osmosis permeator unit #1 and three samples from the plant effluent containing the discharge of the three permeator units. There appears to be little variation in the efficiency of treatment during the early or 5 hour period of treatment. Only a slight increase in hardness and a slight decrease in sulfate content was noted in the plant effluent after five hours of treatment and these values may not be significant.

The literature[20] indicates that a characteristic of essentially all reverse osmosis membranes is that rejection of divalent ions such as Ca Mg and SO_4 is much greater than for the monovalent ions such as Na and Cl. Removal of these divalent ions is in the range of 92 to 99% whereas the removal of the monovalent items is less than 90%. Radium-226 is a divalent ion and the high radium removals of 97 to 96% parallel the hardness, calcium and magnesium removals.

Iron removal by the reverse osmosis unit was from a raw value of 1.6 to 0.3 mg/l or a percentage removal of 81%. This is a lower than expected removal. Total solids were reduced from 2,160 to 99 mg/l in permeator #1 and to 164 mg/l in the combined permeator effluent for removals of 95 and 93% respectively.

While the product water from the permeators contains less than 10% of the total solids which were in the feed, the reject stream from the permeators contains about three times the amount of total solids in the original feed from the deep well. Table 7 lists the operating data for the three permeators during an operating period of 405 minutes. Operation of the three units continued for a total operating time of about 10 hours but samples and operating data were collected during the shorter period.

Table 7
Reverse Osmosis Plant Operating Data
Greenfield, Iowa
August 8, 1974

Unit	Gallons Pumpage	Minutes Operation	Rate gpm	Percent Product	Gallons Reject	Rate gpm	Percent Reject
Permeator #1	20,560	405	33.4	66	7,020	17.3	34
Permeator #2	18,206	405	32.2	72	5,210	12.7	28
Permeator #3	17,590	405	30.8	71	5,100	12.6	29
Total	56,360	405	96.5	69	17,330	42.8	31

The flow rate of 96.5 gpm is slightly less than the design rate of 105 gpm for the three tube permeators. The percent product water or the percent conversion of treated water produced to well water pumped was 69 percent which is within the low product recovery range for municipal installations.

Post treatment of the product water consists of decarbonation by means of an aerator and addition of about 40 mg/l of soda ash to raise the pH to the 7-8 range. Operating control of the permeator is generally by a simple specific conductance test. In addition automatic pH control equipment would shut down the system in the event of loss of chemical feed in order to protect the permeators from damage.

From the standpoint of corrosivity, chemical stability as indicated by saturation with calcium carbonate is the most widely accepted criterion in the classification of a water as "corrosive" or "protective". A minimum alkalinity of 50 to 100 mg/l and a minimum of about 50 mg/l of calcium (expressed as $Ca\ CO_3$) must be present at normal temperatures for protection of water mains by the deposition of a calcium carbonate coating. A positive saturation index is invalid if there is not sufficient alkalinity or calcium present to provide a scale forming film.

The town of Greenfield uses the reverse osmosis treated water to supplement the supply of surface water supply. The reverse osmosis treated water has a calcium content of only about 6 mg/l or about 15 mg/l expressed as calcium carbonate. The mixture of the treated deep well and surface water supply contains sufficient calcium carbonate to minimize water main corrosion by deposition of a calcium carbonate protective coating.

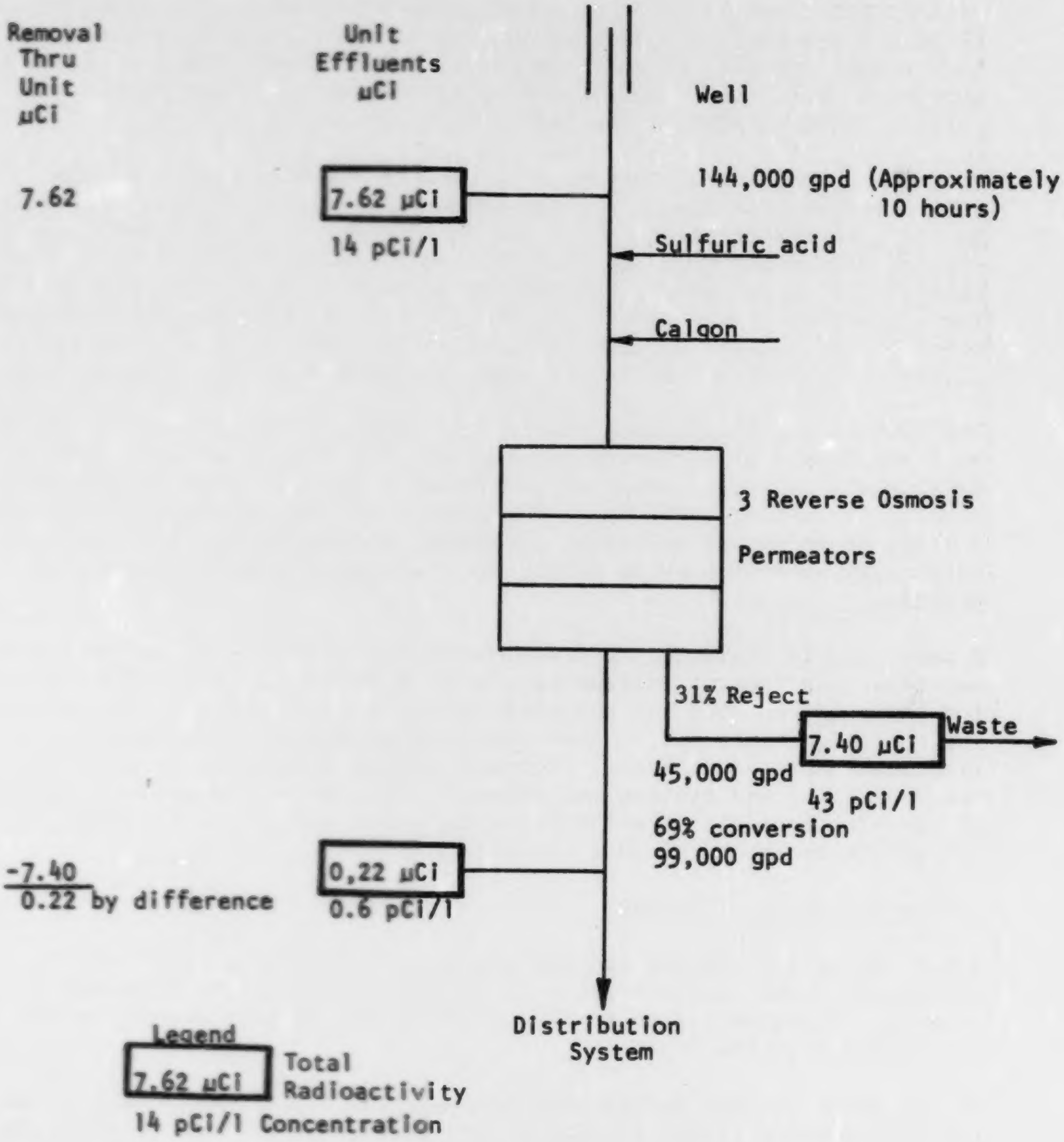
A water supply utilizing reverse osmosis for desalting or radium removal may have insufficient calcium remaining to provide a protective coating for corrosion control and the addition of calcium ions would be necessary for corrosion control. In some cases polyphosphate or sodium silicate treatment might be possible. Economic losses incidental to corrosion of water distribution systems and plumbing fixtures or the serious reduction of carrying capacity of water mains may occur even when corrosion is not active enough to produce red water.

Radium-226 Material Balance

Figure 11 is a schematic drawing showing the treatment units and the radium-226 total radioacitivity at various stages in the treatment process. Detailed radium computations for the 10 hour day are shown in Section B in the Appendix.

Of the total 144,000 gallon well pumpage, 45,000 gallons or 31% is in the reject water stream leaving 99,000 gallons or 69% converted to product water pumped to the distribution system. Applying the 14 pCi/l

Figure 11
Ra-226 Distribution in Treatment Process
Greenfield, Iowa
Reverse Osmosis Desalting Plant
August 8, 1974


Removal
Thru
Unit
µCi
Unit
Effluents
µCi
Well
7.62
7.62 µCi
14 pCi/l
144,000 gpd (Approximately
10 hours)
Sulfuric acid
Calgon
3 Reverse Osmosis
Permeators
31% Reject
7.40 µCi
Waste
45,000 gpd
43 pCi/l
69% conversion
99,000 gpd
-7.40
0.22 by difference
0,22 µCi
0.6 pCi/l
Distribution
System
Legend
7.62 µCi
Total
Radioactivity
14 pCi/l Concentration

concentration value to the well pumpage gives a radium-226 total radioactivity of 7.62 µCi in the well water. Similar calculations show a radium-226 concentration of 43 pCi/l and a total radioactivity of 7.40 µCi in the reject water with a remaining radium-226 concentration of 0.6 pCi/l and a total radioactivity of 0.22 µCi in the product water to the distribution system. It will be noted that subtracting the total radioactivity of 7.40 µCi in the reject water from the 7.62 µCi in the well water leaves a difference of 0.22 µCi in the product water. This latter value was also calculated from the readium-226 concentration remaining in the product water. An excellent material balance of radium-226 through the system was attained.

SECTION 11

IRON AND MANGANESE REMOVAL

SECTION 11.1

PROCESS DESCRIPTION

The presence of iron and manganese, particularly in well supplies, is objectionable primarily because the precipitation of these metals alters the appearance of the water, turning it a turbid yellow-brown color. In addition, the deposition of these precipitates will cause staining of plumbing fixtures and laundry. Another condition which has been associated with the presence of iron and manganese in water supplies has been the growth of microorganisms in distribution systems. Accumulations of microbial growths can lead to reduction of pipeline carrying capacity, resuspension of these deposits causing high turbidities and adverse consumer complaints of tastes and odors.

Because of the nuisances caused by relatively small concentrations of these metals, many groundwater supplies for municipalities require treatment for removal or control of iron and manganese. Where ion exchange softening is employed, iron and manganese are frequently removed prior to exchange because the precipitates formed would cause clogging problems and would coat the exchange media or oxidize after penetration, resulting in a loss of exchange capacity.

The presence of iron and manganese in groundwater is generally attributable to the solution of rocks and minerals, chiefly oxides, sulfides, carbonates and silicates containing these metals. The fact that manganese bearing minerals are less abundant than iron bearing minerals in part accounts for the fact that iron is found more frequently in ground waters. The solution of iron and manganese bearing minerals is often attributed to the action of carbon dioxide in groundwaters. The concentrations of iron and manganese found in solution in natural waters are frequently limited by the solubility of their carbonates, therefore, waters of high alkalinity often have lower iron and manganese contents than those of low alkalinity.

The treatment processes employed in the removal or control of iron and manganese include:

1. Precipitation and filtration
    a. Aeration, detention (or sedimentation) and filtration
    b. Oxidation by potassium permanganate, chlorine or chlorine dioxide

2. Ion Exchange

a. The manganese greensand zeolite process

In water treatment plant practice, the great majority of iron and manganese removal plants employ aeration, detention (or sedimentation) and filtration. In many instances, chlorine is added following aeration to aid in oxidation.

In the oxidation reaction, iron and manganese are first oxidized (iron from Fe^{+2} to Fe^{+3} and manganese from Mn^{+2} to Mn^{+4}) and precipitated as insoluble hydroxides or oxides. Recent studies[21] have shown that, particularly with hard waters, ferrous carbonate ($FeCO_3$) can be expected to precipitate and then remain unoxidized, meaning that filters in iron removal plants may be removing ferrous carbonate rather than ferric hydroxide. The oxidation of manganese (Mn^{+2} to Mn^{+4}) by dissolved oxygen is much slower than the oxidation of Fe^{+2} and is very slow at a pH less than 9.5. Chemical oxidation of Mn^{+2} is generally required to achieve precipitation of MnO_2 in pH ranges common to waterworks practice. Potassium permanganate will oxidize the manganous ion to manganese dioxide rapidly (within 5 minutes) over a broad pH range.

The removal or iron and manganese on continuously regenerated permanganate greensand filters is practiced by continuously adding the potassium permanganate to the water prior to passage through a bed of zeolite (greensand exchange media. The permanganate oxidizes the iron and manganese so that the exchange medium becomes coated with oxidation products. The hydrous oxides of iron and manganese deposited on the exchange medium have a large sorption capacity for Fe^{+2} and Mn^{+2}.

Sorption reportedly plays a significant role in the removal of iron and manganese from solution. Precipitates of hydrous oxides of Fe^{+3} and manganese dioxide both have high sorption capacities for Fe^{+2} and Mn^{+2}. This phenomenon may account for the removal of iron and manganese on contact filters as well as within filters where the filter medium is coated with precipitate. A period of "aging" is required for the deposition of the precipitate to take place.

Sedimentation is rarely specifically provided unless the concentrations of iron and manganese in the raw water is quite high (>10 mg/l). Generally, little sedimentation occurs in detention tanks and instead are considered to be quiescent reaction basins.

SPECIFIC PROCESSES

Iron and manganese removal is utilized in some form of pretreatment for the four ion exchange softening plants and as the only removal process at two other plants selected for the study. This information is summarized in Table 8.

TABLE 8

Iron and Manganese Removal Processes

Municipality	Detention	Type Filter	Media
Iron & Manganese Removal Only			
Adair	140 min.	Pressure	Greensand
Stuart	24 hour	Pressure	Anthrafilt
Ion Exchange Pretreatment			
Eldon	7min.	Pressure	Anthrafilt
Estherville	None	Gravity	Anthrafilt
Grinnell	24 hour	None	
Holstein	2 hour	Pressure	Anthrafilt

SECTION 11.2

ADAIR

BACKGROUND INFORMATION

Adair is located on the northern border of Adair County in southwest Iowa with the northern portion of the City lying in Guthrie County. Both counties have experienced population outmigration due to advances in agriculture and farm consolidation. Adair had experienced significant population decreases until the 1960-1970 period when construction of the adjacent interstate highway stimulated the development of light industry. The 1970 population is 750 with projected moderate future population increases.

EXISTING WATER FACILITIES

Adair obtains its water supply from two deep wells called the "old dry well" or Well No. 1 and the "Jordan well" or Well No. 3. The wells are described as follows:

WELL WATER SUPPLY - ADAIR

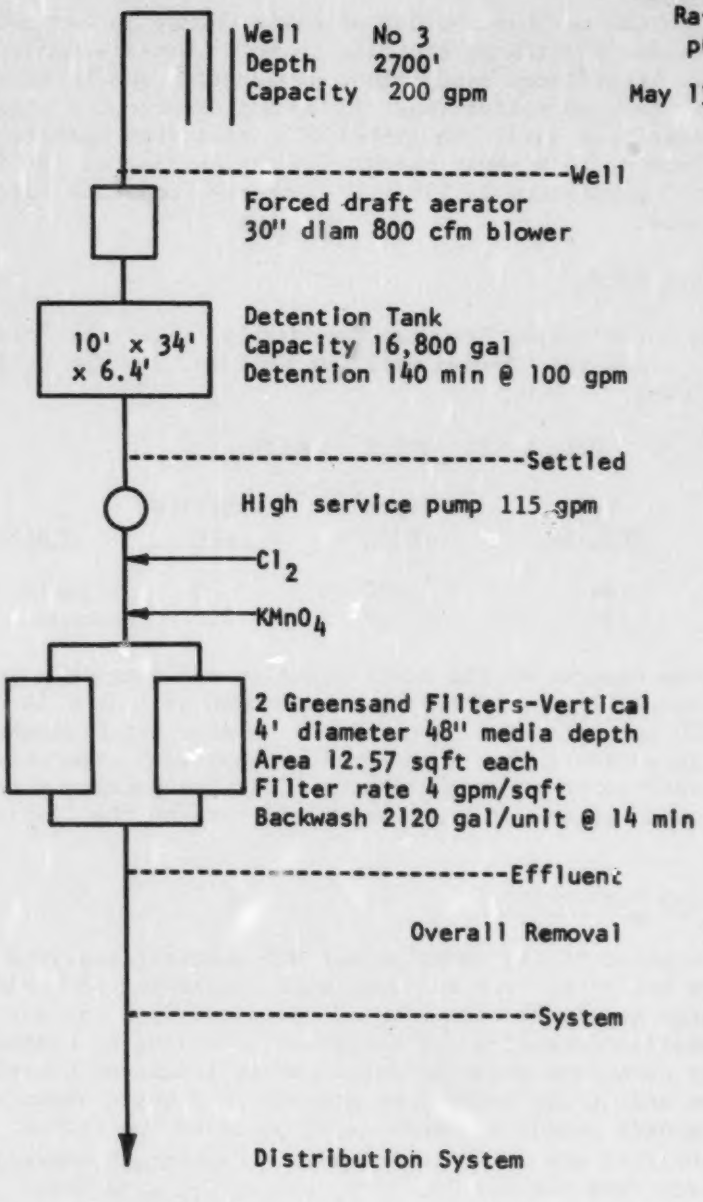
Well No.	Year Drilled	Depth Feet	Capacity gpm	Aquifer
1	1941	1,728	60	Silurian-Devonian
3	1967	2,700	200	Jordan

Figure 12 is a flow diagram of the Adair aeration and manganese greensand iron removal pressure filter. Normally, the Jordan well only is used and is pumped at a 200 gpm rate to a forced draft aerator which discharges to a 17,000 gallon detention tank. High service pumps with capacities of 115 gpm pump the aerated water after continuous potassium permanganate dosage through two manganese greensand iron removal filters to the distribution system.

MANGANESE GREENSAND PERFORMANCE

Table 9 is a tabulation of the radiological and chemical analysis performed on samples collected from the deep well furnishing the principal source of raw water supply for the town of Adair and from the various stages in the aeration detention and manganese greensand filtration. A second survey was conducted when the first survey indicated extremely low removal of radium and it was determined grossly inadequate amounts of potassium permanganate regenerant were being added to the filter. Additional mineral analyses are shown in Appendix. Percentage removals of radium-226 and iron from the May 13, 1975, survey are also shown on plant flow diagram, Figure 12.

Figure 12
Flow Diagram
Adair, Iowa - Population 750 (1970)
Greensand Iron Removal Plant


Well No 3
Depth 2700'
Capacity 200 gpm
Well
Forced draft aerator
30" diam 800 cfm blower
10' x 34' x 6.4'
Detention Tank
Capacity 16,800 gal
Detention 140 min @ 100 gpm
Settled
High service pump 115 gpm
Cl_2
$KMnO_4$
2 Greensand Filters-Vertical
4' diameter 48" media depth
Area 12.57 sqft each
Filter rate 4 gpm/sqft
Backwash 2120 gal/unit @ 14 min
Effluent
System
Distribution System

	Parameter and Removal Efficiency	
	Ra-226 pCi/l	Iron mg/l
	May 13, 1975	
Well	13	1.1
Detention Tank	13	1.2
Settled	0%	0%
Effluent	8	0.02
Overall Removal	38%	98%
System	7.5	0.32

Table 9
Radiological and Chemical Analysis
Adair, Iowa Water Supply
September 16-18, 1974*

Sampling Point	Gross Alpha pCi/l	Ra 226 pCi/l	Hard-ness mg/l	Total Solids mg/l	Alkalinity		pH	Iron		Ca mg/l	Mg mg/l	Na mg/l	Mn mg/l	Cl mg/l	SO4 mg/l
					P mg/l	T mg/l		Total mg/l	Sol mg/l						
Well #3 2700' 1/2 hr	14	6.9			0	240	7.4	0.41	0.05				<0.01		
Well #3 2700' 6 hr	16	6.3	710	1921	0	164	7.5	0.58	0.04	180	70	330	0.01	330	780
Green Sand Filter Inf 6 hr	9.3	6.9				159	7.45	0.01	0.01				<0.01		
Green Sand Filter Inf 6 hr	6.8	6.9	710	1880	0	161	7.45	0.10	0.01	170	70	330	<0.01	360	760
Green Sand Filter Eff 1 hr	13	6.7				157	7.45	0.77	0.05				<0.01		
Green Sand Filter Eff 25000	10	7.7	700	1896	0	158	7.45	0.17	0.01	180	66	330	0.01	350	760
Green Sand Filter Eff 50%	11	6.7				158	7.5	0.02	0.01				<0.01		
Green Sand Filter Eff 50% Dup	16	6.0			0	156	7.45	0.02	0.01				<0.01		
Green Sand Filter BW 2 min	330	250	710	2057	0	163	7.4	64		170	70	330	3.1	370	770
Green Sand Filter BW 4 min	92	84			0	178	7.4	23					1.0		
Green Sand Filter BW 8 min	89	65			0	169	7.45	20					0.81		
Distribution System	11	7.5					7.4	0.32					<0.01		
May 12, 1975 Survey															
Well #3 8 hr Comp	16	13	680	1890	0	164	7.6	1.1					0.01		
Filter Inf 8 hr Comp	16	13	680	1890	0	164	8.0	1.2					0.01		
Filter Eff 8 hr Comp	14	8.0	680	1900	0	162	7.8	0.02					0.04		
Filter BW 5 hr Comp	200	190	815	2040	0	200	7.75	59					3.6		

*Iron caps used on sample collection bottles on this survey and some iron results may be in error.
In addition there may have been a mixup in bottle numbers

The second survey was undertaken during May, 1975, to determine removals with a properly regenerated manganese greensand filter. Iron removals were checked following an initial regeneration period and an increased theoretical dosage for continuous regeneration. During an inspection of the two filters it was discovered that one filter was completely caked with a hole in the supporting gravel over the underdrain resulting in no backwashing of the media or filtration through the media. Figure 13 shows one of the Adair greensand filters.

Figure 13

Adair Greensand Filter

Following an attempt to break up the caked greensand it was discovered that upon filtration the media was passing out the effluent and the unit was shut down for future repairs. All flow was then passed through a single filter at a filtering rate of 8 -9 gpm/sq. ft. during the second survey.

Composite samples collected from the well and greensand filter influent and effluent are shown in Table 9. Field iron determinations were made at time of compositing to insure reasonably good iron removal was taking place.

WELLS

September 16-18, 1974

During the early survey, samples collected from the well at 30 minute and 6 hour intervals showed a slight decrease in radium-226 activity from 6.9 to 6.3 pCi/l after the longer pumping period as shown in Table 9. At the end of the longer pumping period hardness in the well water was 710 mg/l, total solids 1921 mg/l, chlorides 330 mg/l, total iron o.51 mg/l, and manganese 0.01 mg/l. Table 10 lists the concentrations and percentage removals of these pertinent radium and chemical constituents through the iron removal units

May 13, 1975

A well composite collected over a 6 hour period on this date showed a marked increase in radium-226 content to 13 pCi/l when compared with the 6.9 and 6.3 pCi/l concentrations on the original survey. No valid reason can be given for the increase except for changes in pumping rates as compared with the earlier survey. The deep well was shut down for a three day period a week before the second survey due to a pump motor failure. Well pumpage rate was in the 150,000 gpd rate at the time of the second survey due to an undetected main leak as compared with a 100,000 gpd rate during the earlier survey. These pumping rates may have affected the vertical recharge of the well formation.

TABLE 10

Radium-226 and Iron Removals

Continuously Regenerated Greensand Filter

Adair, Iowa

Sampling Point	Ra-226 pCi/l	Ra-226 Percent Removal	Total Iron mg/l	Total Iron Percent Removal
September 16. 1974				
Well Supply	6.6	-	0.50	
Detention Tank Effluent	6.9	-	0.10	80
Greensand Filter Effluent	6.3	-	0.07	43
Overall Removal		5		32
System	7.5		0.32	-
May 13, 1975				
Well Supply	13	-	1.1	
Detention Tank Effluent	13	0	1.2	-
Greensand Filter Effluent	8	38	0.02	98
Overall Removal		38		98

Detention Tank

September 16-18, 1974

Iron removal analyses are not considered reliable due to possible collection errors and iron caps on the sample bottles.

May 13, 1975

Determinations made on composite samples during the May survey indicated no removal of iron or radium-226 through the detention tank.

MANAGESE GREENSAND FILTER

September 16, 1974

Radiological and chemical analyses were collected at intervals through the usual greensand filter run as indicated in Table 10. Radium showed some variations and a representative average indicated a radium-226 reduction from 6.6 pCi/l in the well supply to 6.3 pCi/l for a reduction of only 5%. Iron values dropped to an average range of 0.07 mg/l.

May 13, 1975

Total iron values on the May Survey were reduced from 1.1 mg/l in the composite of the greensand filter effluent for an excellent overall removal of 98 percent. Likewise, the radium-226 content in the effluent was reduced to 8 pCi/l from 13 pCi/l in the well water for an overall radium reduction of 38 percent. Therefore, it appears that proper potassium permanganate dosage of the manganese greensand filter greatly improved the iron oxidation and removal with a concurrent improvement in radium removal. This removal was being accomplished with a single greensand filter operating at double the normal filtering rate.

After a week of continuous regeneration of the manganese greesand filter at the theoretical potassium permanganate dosage, the filter effluent composite showed a manganese content of 0.04 mg/l. A faint pink color due to potassium permanganate was evident in some of the individual composite filter effluent samples collected during the day. The concentration of the potassium permanganate feed solution was reduced somewhat by dilution and the pink color disappeared n the filter effluent samples.

RADIUM-226 MATERIAL BALANCE

Figures 14 and 15 are schematic drawings showing the water treatment units and the radium-226 total radioactivity and concentrations at various stages in the treatment process from data on the two surveys conducted in September, 1974, and May,1975. Detailed computations are included in the Appendix B.

September 18, 1974

Applying the 6.6 pCi/l radium concentration value to the well pumpage over a two-day pumpage period gives a total radium-226 radioactivity of 5.3μCi in the well water supplied to the filter. There was no reduction following aeration and detention.

The radium-226 total radioactivity of 1.2 μCi in the manganese greensand filter was the activity accumulated in the filter during the two-day filter run and was calculated by using the composite pCi/l concentration in the filter backwash. This 1.2 μCi value in the greensand filter effluent. Thus, there was a fair meterial balance of radium-226 through the treatment units.

Figure 14
Ra-226 Distribution in Treatment Process
Adair, Iowa
Greensand Iron Removal Plant
September 18,1974

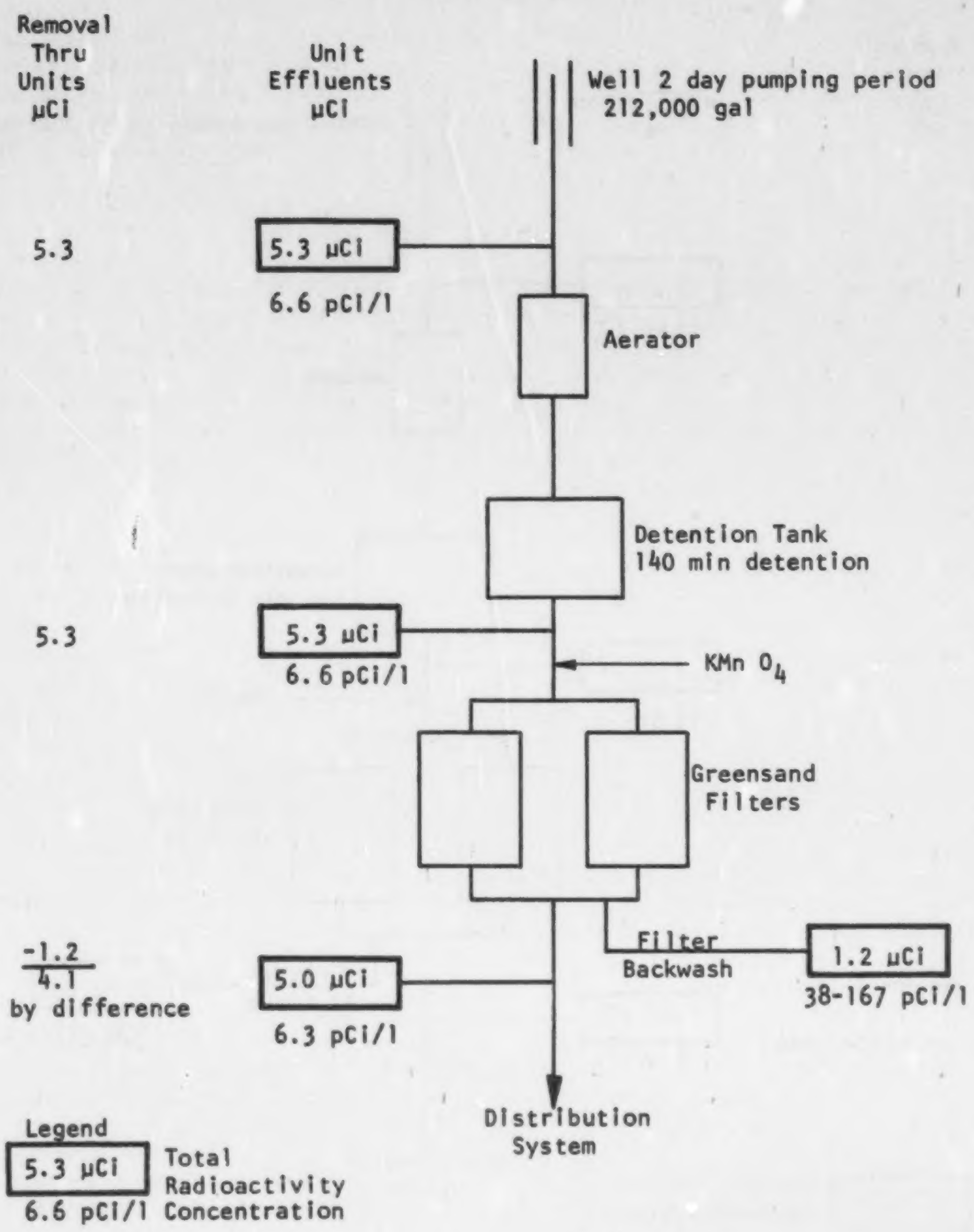
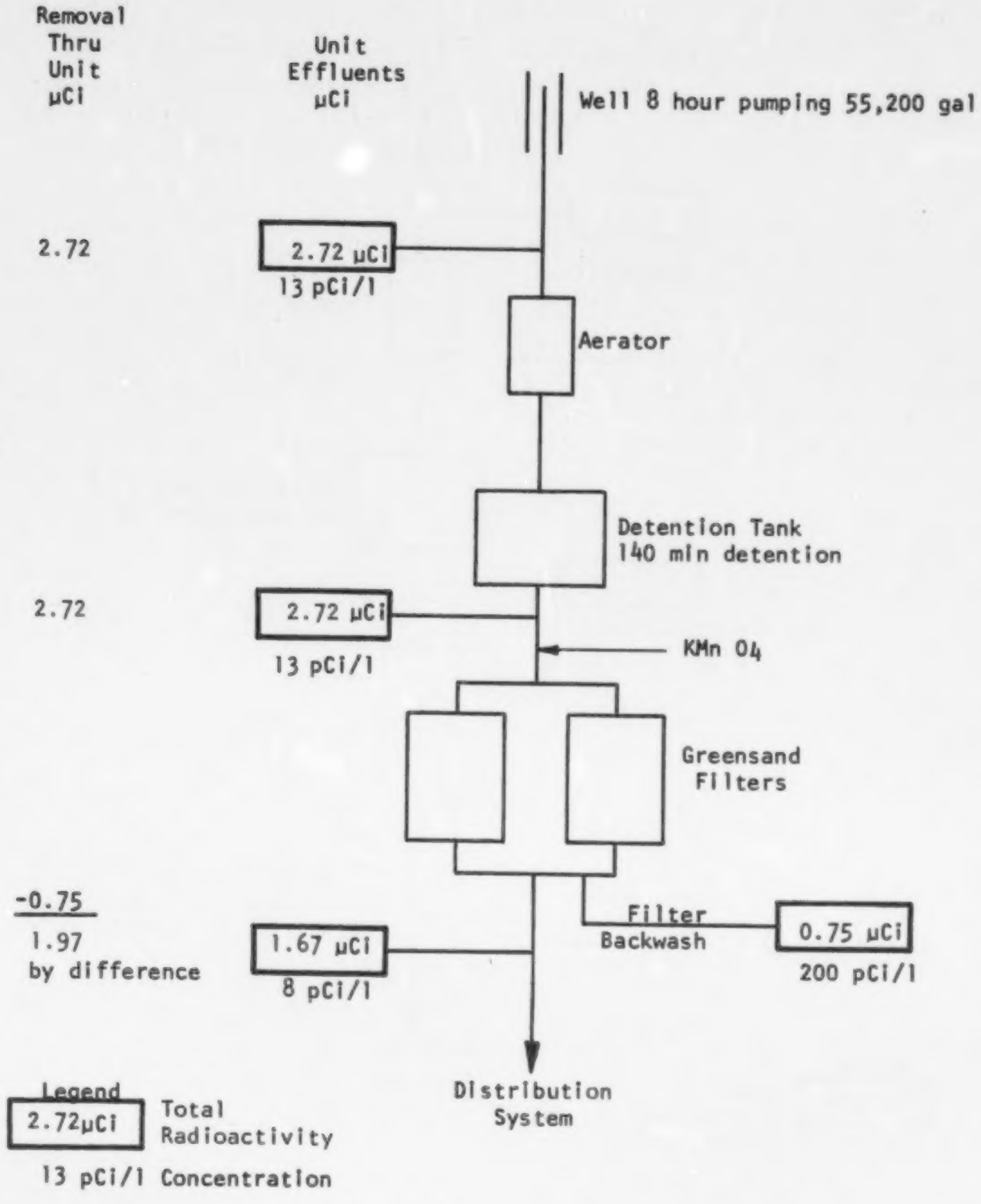

Removal Thru Units µCi
Unit Effluents µCi
Well 2 day pumping period 212,000 gal
5.3
5.3 µCi
6.6 pCi/l
Aerator
Detention Tank 140 min detention
5.3
5.3 µCi
6. 6 pCi/l
KMn O_4
Greensand Filters
Filter Backwash
1.2 µCi
38-167 pCi/l
-1.2
4.1
by difference
5.0 µCi
6.3 pCi/l
Distribution System
Legend
5.3 µCi
6.6 pCi/l
Total Radioactivity Concentration

Figure 15
Ra-226 Distribution in Treatment Process
Adair, Iowa
Greensand Iron Removal Plant
May 13, 1975


Removal Thru Unit µCi
Unit Effluents µCi
Well 8 hour pumping 55,200 gal
2.72
2.72 µCi
13 pCi/l
Aerator
Detention Tank
140 min detention
2.72
2.72 µCi
13 pCi/l
KMn O4
Greensand Filters
-0.75
1.97
by difference
1.67 µCi
8 pCi/l
Filter Backwash
0.75 µCi
200 pCi/l
Distribution System
Legend
2.72µCi
Total Radioactivity
13 pCi/l Concentration

May 13, 1975

The radium-226 concentration in the well water nearly doubled to a value of 13 pCi/l and there was a substantial reduction of radium concentration through the manganese greensand filter which was receiving proper potassium permanganate dosage during this survey.

The 13 pCi/l concentration applied to the eight hour well pumpage period gives a total radium-226 radioactivity of 2.72 µCi which is also the total radioactivity in the detention tank effluent discharging to the greensand filter.

A total radium-226 radioactivity of 2.05 µCi was accumulated in the filter backwash during the filter run of 150,470 gallons before backwash. Only 55,200 gallons were filtered during the 8 hour sampling period for the other plant units and the 2.05 µCi was proportioned to give a 0.75 µCi total radioactivity accumulated in the filter backwash during the shorter period. This radioactivity removed by the backwash when subtracted from the greensand filter effluent radioactivity gives a calculated radium-226 radioactivity of 1.97 µCi compared with the value of 1.67 µCi in the greensand filter effluent. This is a fair material balance through the treatment system.

SECTION 11.3

STUART

BACKGROUND INFORMATION

Stuart is located on the northeastern border of Adair County in southwest Iowa with the northern portion of the town located in Guthrie County. Both counties have experienced population outmigration due to farm consolidation and, as a result, the Town of Stuart has also had a significant decrease to a 1970 population of 1,354 persons.

EXISTING WATER FACILITIES

Stuart presently derives its public water supply from a 2,801 foot deep Jordan formation well constructed in 1962. Figure 16 is a flow diagram of the Stuart iron removal plant. The 300 gpm well transfers water to a forced draft aerator location on top of the 150,000 gallon concrete surface detention and settling tank. Transfer pumps of 300 gpm capacity pump the settled water from the surface storage reservoir through a four-cell horizontal pressure iron removal filter provided with anthracite media. High service pumps of 300 gpm capacity pump from a 150,000 gallon concrete surface clearwell to the distribution system. The iron removal filters are shown in Figure 17.

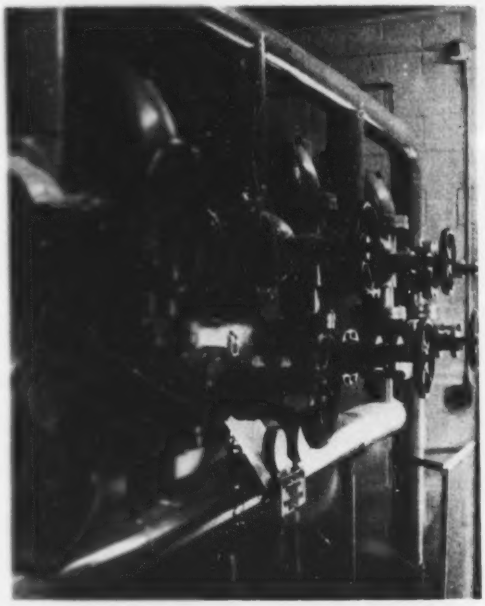
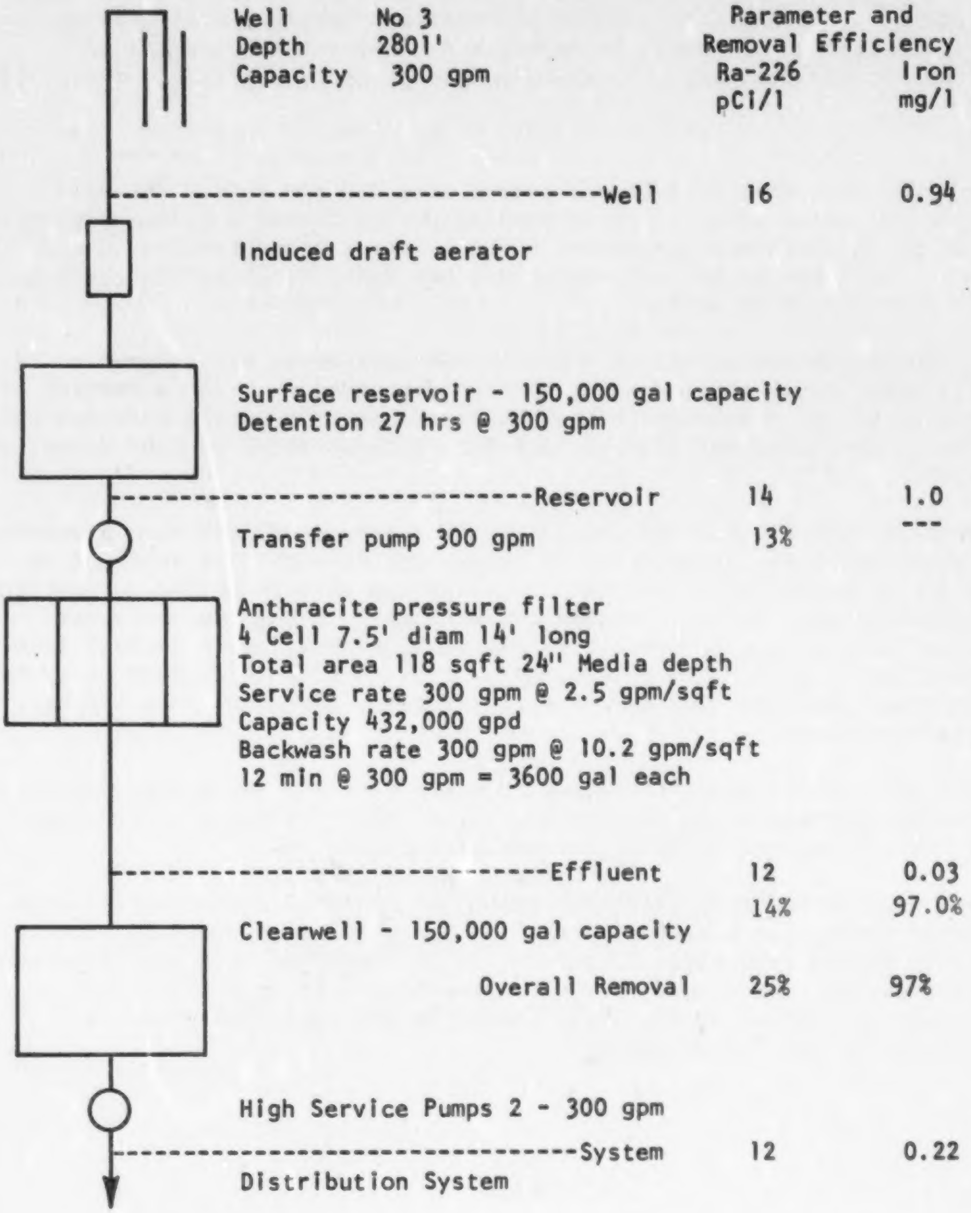


Figure 17

Stuart Iron Removal Filters

Figure 16
Flow Diagram
Stuart, Iowa - Population 1,354 (1970)
Pressure Filter - Iron Removal Plant


Well No 3
Depth 2801'
Capacity 300 gpm
Parameter and Removal Efficiency
Ra-226 pCi/l
Iron mg/l
Well 16 0.94
Induced draft aerator
Surface reservoir - 150,000 gal capacity
Detention 27 hrs @ 300 gpm
Reservoir 14 1.0
13% ---
Transfer pump 300 gpm
Anthracite pressure filter
4 Cell 7.5' diam 14' long
Total area 118 sqft 24" Media depth
Service rate 300 gpm @ 2.5 gpm/sqft
Capacity 432,000 gpd
Backwash rate 300 gpm @ 10.2 gpm/sqft
12 min @ 300 gpm = 3600 gal each
Effluent 12 0.03
14% 97.0%
Clearwell - 150,000 gal capacity
Overall Removal 25% 97%
High Service Pumps 2 - 300 gpm
System 12 0.22
Distribution System

AERATION, SEDIMENTATION AND FILTRATION PERFORMANCE

Table 11 is a tabulation of the radiological and chemical analyses performed on samples collected from the 2,801 foot #3 deep well furnishing the raw water supply for the town of Stuart and from the various stages in the aeration and iron removal filtration process. Additional mineral analysis results are shown in Appendix A. Percentage removals of radium-226 and iron are also shown on the plant flow diagram, Figure 16.

Well

The 2,801 foot deep #3 well was pumped at a 300 gpm rate. The well sample collected after a 5-hour pumping period showed a radium-226 content of 16 pCi/l which was the second highest radium concentration in the study. Hardness in the well water was 640 mg/l, total solids 1,770 mg/l and total iron 0.94 mg/l.

The radium-226 content of 16 pCi/l in the well water was reduced to 14 pCi/l after passage through the 7-hour detention tank for a removal of 13 percent. No reduction in iron content concurred during aeration and settling in the ground storage tank with a theoretical 24-hour detention period.

Radium-226 was further reduced in the iron removal filter from a value of 14 to 12 pCi/l for a reduction of 14 percent through this unit and an overall reduction of 25 percent of radium-226 through aeration, settling and filtration. The iron content of 0.94 mg/l in the raw water was reduced by the same treatment process to 0.03 mg/l for an overall iron removal of 97 percent. The 0.22 mg/l of iron in the distribution system sample may indicate iron pickup from the water mains due to a slightly aggressive water.

There were no significant changes in other chemical parameters during the aeration, detention and filtration. Iron removal efficiency remained the same (97 percent) during the two week filter run.

These results indicate that some amount of radium-226 concentration is removed during the aeration, detention and filtration process. The overall radium removal of 25 percent is low compared with the 97 percent iron removal. The manner of radium removal on the iron filter is possibly adsorption or catalytic action by the oxijation products deposited on the filter media.

Table 11
Radiological and Chemical Analysis
Stuart, Iowa Water Supply
October 22, 1974

Sampling Point	Gross Alpha pCi/l	Ra 226 pCi/l	Hard-ness mg/l	Total Dis Solids mg/l	Alkalinity		pH	Iron		Ca mg/l	Mg mg/l	Na mg/l	Mn mg/l	Cl mg/l	SO4 mg/l
					P mg/l	T mg/l		Total mg/l	Sol mg/l						
Well #3 2801' 5 hr	32	16	640	1770	0	182	7.6	0.94	0.94	150	62	310	0.01	240	780
Detention Tank 5 hr	24	14	640	1760	0	182	7.9	1.0	1.0	150	62	300	0.01	260	790
Detention Tank 20 hr	16	13	640	1780	0	182	7.9	1.0	1.0	150	62	310	0.01	240	780
Iron Filter Eff 2 hr	15	12	640	1760	0	174	7.6	0.03	0.03	150	62	300	0.01	250	780
Iron Filter Eff 2 wk	14	12	630	1760	0	174	7.6	0.03	0.03	150	61	310	<0.01	250	780
Iron Filter Backwash 2 min	340	230	630	2178	0	186	7.6	120	120	160	62	310	0.23	260	790
Iron Filter Backwash 12 min	180	120	630	1924	0	178	7.6	93		160	62	310	0.67	250	780
Distribution System	23	12	620	1740	0	170	7.6	0.22	0.22	150	62	310	0.01	250	780

The iron removal filter backwash accumulated high concentrations of radioactivity and iron during the two week filter run. Radium-226 concentration increased to values of 230 and 120 pCi/l at 2 minute and 12 minute intervals respectively during the backwash period. Likewise, the iron concentrations increased to 120 and 93 mg/l at these same intervals during the backwash period.

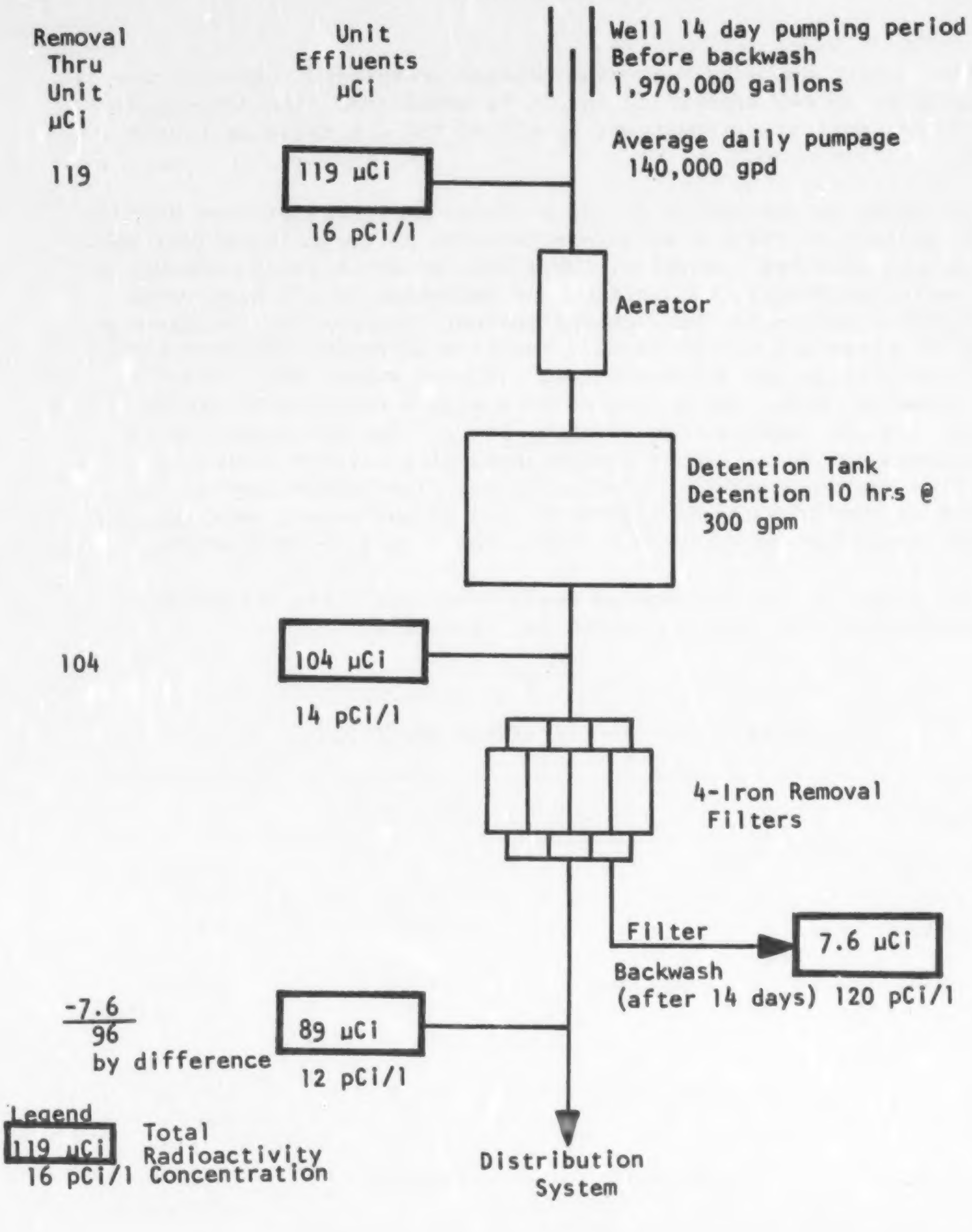
RADIUM-226 MATERIAL BALANCE

Figure 18 is a schematic drawing showing the water treatment units and the radium-226 total radioactivity and concentrations at various stages in the treatment process. The detailed computations are included in the Appendix B.

Applying the 16 pCi/l radium concentration value to the well pumpage of 1.97 million gallons during the two week iron filter run gives a total radium-226 radioactivity of 119 µCi in the well water pumped. The radium-226 total radioactivity calculated from the 14 pCi/l concentration in the detention tank effluent was 104 µCi for a reduction of 13 percent.

The radium-226 total radioactivity of 7.6 µCi in the iron removal filter backwash was the radioactivity accumulated in the filter during the 14 day filter run and was calculated by using the composite 120 pCi/l concentration in the filter backwash. This 7.6 µCi/l radioactivity value subtracted from the detention tank activity value should have equalled the activity in the iron removal filter effluent. The calculated radium-226 radioactivity value of 96 µCi/l compares with an activity value of 89 µCi in the filter effluent. Thus there was a fair material balance of radium-226 through the treatment units.

Figure 18
Ra-226 Distribution in Treatment Process
Stuart, Iowa
Aeration and Iron Removal Filter Plant


Removal Thru Unit µCi
Unit Effluents µCi
Well 14 day pumping period
Before backwash
1,970,000 gallons
Average daily pumpage
140,000 gpd
119
119 µCi
16 pCi/l
Aerator
Detention Tank
Detention 10 hrs @ 300 gpm
104
104 µCi
14 pCi/l
4-Iron Removal Filters
Filter Backwash (after 14 days)
7.6 µCi
120 pCi/l
-7.6
96
by difference
89 µCi
12 pCi/l
Legend
119 µCi
16 pCi/l
Total Radioactivity
Concentration
Distribution System

SECTION 12

SODIUM CATION EXCHANGE

SECTION 12.1

PROCESS DESCRIPTION

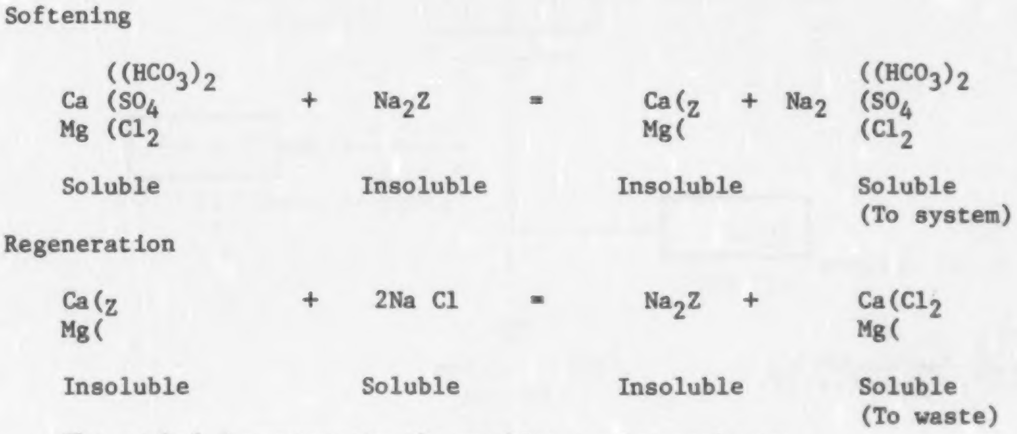
The sodium cation exchange softening process is employed by four of the municipalities in the study. It should be noted that iron removal is employed as a part of pretreatment by all of the ion exchange plants studied.

Water softening by the sodium cation exchange (zeolite) process depends upon the ability of certain soluble substances to exchange cations with other cations dissolved in water. When hard water is passed through a sodium cation exchanger, the calcium and magnesium in the hard water is replaced by sodium in the exchange medium. Because the reaction is reversible, after all of the readily replaceable sodium has been exchanged for calcium and magnesium from the hard water, the "exhausted" cation exchange medium can be regenerated with a solution of sodium chloride. In the regeneration process, the calcium and magnesium of the exhausted cation exchanger are replaced with a fresh supply of sodium from the regenerating brine solution. Then after washing to free it from the calcium and magnesium cations and excess salt the regenerated exchanger is ready to soften a new supply of hard water.

Using the symbol Z for the complex zeolite radical[22] the softening and regeneration reactions are shown in Figure 19.

Figure 19

SODIUM CATION ION EXCHANGER REACTIONS



Softening

$$\begin{array}{ll} & ((HCO_3)_2 \\ Ca & (SO_4 \\ Mg & (Cl_2 \end{array} + Na_2Z = \begin{array}{l} Ca(_Z \\ Mg(\end{array} + Na_2 \begin{array}{l} ((HCO_3)_2 \\ (SO_4 \\ (Cl_2 \end{array}$$

Soluble	Insoluble	Insoluble	Soluble (To system)

Regeneration

$$\begin{array}{l} Ca(_Z \\ Mg(\end{array} + 2Na\ Cl = Na_2Z + \begin{array}{l} Ca(Cl_2 \\ Mg(\end{array}$$

Insoluble	Soluble	Insoluble	Soluble (To waste)

The symbol Z represents the zeolite or ion exchange medium radical.

Radium-226 is a divalent cation which is also removed in the exchange process.

The calcium bicarbonates are converted into sodium bicarbonate which when heated in a water heater breaks down into sodium carbonate and strongly corrosive free carbon dioxide gas. Sodium cation exchange softened water, therefore, is corrosive and pH adjustment for stabilization is accomplished by addition of an alkali.

The use of the term Zeolite has been loosely applied to all ion exchange materials which have been used for water softening. They have included greensand, bentonitic clay, synthetic gel-type mineral, sulfonated coal and the synthetic organic resins. Only the naturally occurring New Jersey greensand and the synthetic polystyrene resins will be considered in this discussion.

Natural greensand (glauconite) is found principally in a commercial deposit in New Jersey. It has an exchange capacity of 3,000 grains of hardness per cubic foot of media which is only a tenth of the capacity of the newer synthetic polystyrene resins. It has the feature of removing ferrous iron and manganese ions during softening and is also commonly used for removal of iron and manganese by regeneration with potassium permanganate.

Practically all of the present ion exchange media used in softening are the polystyrene resins which, were patented by D'Alelio in 1945. These resins are produced by the polymerization of styrene monomer with divinyl benzene (DVB) and the resulting resin particle beads are made ion exchange active by sulfonation.

TABLE 12

Operating Characteristics of Polystyrene Ion Exchange Resin[23]

	Range
Operating exchange capacity kgr/cu ft	20-35
Recommended bed depth, inches	24-48
Softening flow rate, gpm/sq ft	4- 8
Softening flow rate, gpm/cu ft	2- 6
Backwash flow rate, gpm/sq ft	5- 6
Salt dosage, lbs/cu ft	5-20
Brine concentrations, %	8-16
Regeneration brine contact time, min	25-45
Rinse flow rate, gpm/cu ft	
Slow	1- 2
Fast	3-5
Rinse requirements gal/cu ft	20-40

Conformance with these operating conditions or other design parameters was determined to indicate whether proper performance and efficiency of the softener unit could be expected at time of sampling. Some operating difficulties and unusual conditions were encountered during some of the study sampling periods but it is believed final results were not seriously affected.

Since the whole depth of the softener unit is involved in the ion exchange, a rate of flow in terms of unit volume is more significant. On completion of the softening cycle, the softener is backwashed in an upflow direction to remove particulates from the top of the bed, loosen the resin and regrade to assist in regeneration.

All ion exchange softeners in the study were of the pressure type in vertical steel shells. In regenerating the pressure softener, brine in a downflow direction is introduced to the bed at a controlled rate generally through a distribution system set immediately above the exchanger media surface. For the sodium cycle, the exchange capacity of the polystyrene resin for the usual, most economical operating range is from 20 to 27 kilograins of hardness per cubic foot expressed as $CaCO_3$. Low dosages of salt in the 6-10 lb/cu ft range result in the most efficient regeneration, provided there is no short circuiting. There is also an optimum 10-15 percent concentration of brine to produce the maximum exchange capacity. For this brine concentration, a flow rate of 1-2 gpm/cu ft is necessary to secure adequate contact time of the brine with the exchanger media. Rinse water is then applied until the chloride and hardness have been reduced to a level where the unit can be returned to service. The water used to rinse the exchanger is the raw water being treated by the exchanger. It has been determined that 20-40 gallons of water per cubic foot of resin will be needed for rinsing.

After completion of the regeneration cycle, the softener is returned to service and the raw hard water is passed through the unit until a predetermined hardness breakthrough appears in the effluent. In most municipal systems, the softened water is blended with unsoftened water to produce an intermediate hardness effluent and provide a calcium carbonate content for deposition of a protective calcium coating in the water mains. There appear to be no deleterious effects from almost complete exhaustion of the resins. Blending of hard water with the softened effluent is generally accomplished by means of a hard water bypass proportioning system.

The composition of the influent water may have an effect on the capacity and hardness leakage of the resin. Hardness alone in the influent water has little effect on the capacity of the resin. As the sodium content of the effluent water increases, competition develops between the sodium and hardness ions for active sites on the resin and there will be a decrease in capacity and an increase in hardness leakage of the softener.

Iron in the softener feedwater, in either the precipitated or solution form, will seriously affect the exchange capacity. Iron in the ferrous (unoxidized) form will be removed by ion exchange but some iron ions deep within the structure of the resin particle may be oxidized to a stable nonexchangeable form. Most iron oxidized prior to softening will be filtered out and removed during backwashing but there may be serious loss in exchange capacity.

Manganese in natural waters will also cause resin fouling and loss in exchange capacity. Usually manganese is present in lower concentrations and therefore may not be as troublesome as iron.

Iron, manganese and other chemical fouling can be minimized in the operation of municipal softeners by pretreating the water. Methods which may be used include; (1) aeration and filtration, (2) chemical coagulation or oxidation and filtration, (3) chlorination and filtration or (4) use of manganese greensand filters without pretreatment.

In many of the smaller towns the zeolite regeneration procedure is made completely automatic with the addition of an automatic multiport valve. This valve is rotated through the operating positions of service, backwash, regeneration and rinsing by an eletric motor and a system of electrical controls.

SECTION 12.2

ELDON

BACKGROUND DATA

Eldon is located in Wapello County in south central Iowa. Eldon has a population of 1,319 persons and is primarily agriculture service oriented.

EXISTING WATER FACILITIES

Eldon presently derives its public water supply from a 1,901 foot deep Jordan well drilled in 1961. Figure 20 is a flow diagram of the Eldon iron removal and zeolite softening plant. Raw water from the deep well No. 8 is pumped by a 200 gpm capacity pump through a forced draft aerator to a 1,500 gal. detention tank. High service pumps then discharge to a four-cell anthracite pressure iron removal filter to two vertical zeolite softeners (figure 21) and to the system.

Unsoftened water is added to the softened ion exchange softener effluent to provide sufficient calcium carbonate for deposition of a protective coating on the water mains.

Iron filter backwash and softener backwash and spent brine rinse are discharged to a storm sewer with eventual discharge to the Des Moines River.

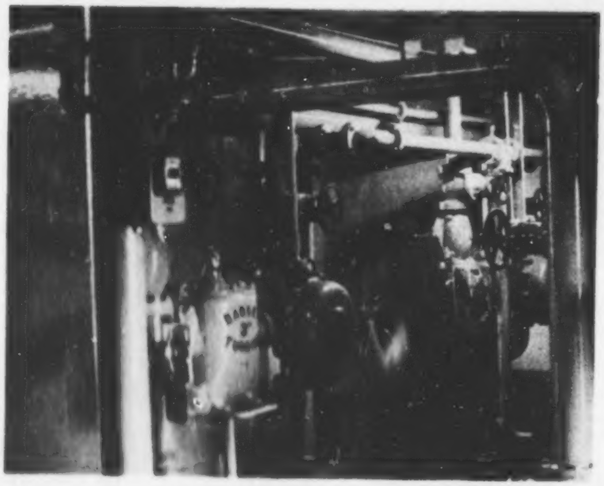
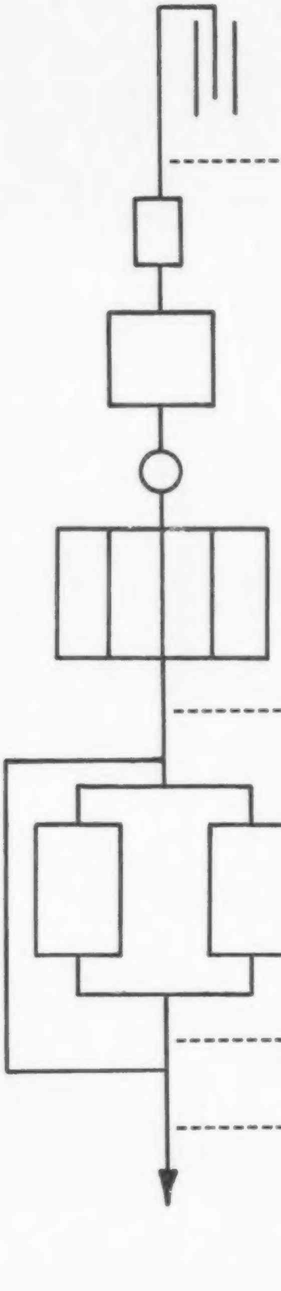


Figure 21
Eldon Ion Exchange Softeners

IRON FILTER AND ION EXCHANGE PERFORMANCE

Table 13 is a tabulation of the radiological and chemical analyses performed on samples collected from the deep well furnishing the raw water

Figure 20
Flow Diagram
Eldon, Iowa Population 1319 (1970)
Pressure Iron Removal Filter and Zeolite Softener Plant



Well No 8
Depth 1901
Capacity 200 gpm

Forced draft aerator

Detention Tank
1500 gal capacity
Detention 7 min @ 200 gpm

High service pump 200 gpm

Anthrafilt pressure filter
4 - Cell 8' diam 14' length
Total area 112 sqft Unit 28 sqft
Service rate 200 gpm 1.8 gpm/sqft
Backwash rate 250 gpm 9.0 gpm/sqft

Zeolite softeners - Vertical
2 Cell 72" diam 9' height
Unit area - 28 sqft 45" media
Unit Volume 107 cuft
Unit Capacity 106,000 gal
Service rate 75 gpm 2.8 gpm/sqft
Backwash rate 90 gpm 3.2 gpm/sqft

Distribution System

	Parameter and Removal Efficiency		
	Ra-226 pCi/l	Hardness mg/l	Iron mg/l
Well	49	375	2.0
Iron Filter Effluent	43 12.2%	360	0.3 85%
Softener Effluent	1.9 96%	10 97%	0.05 83%
Overall Removal	96%	97%	98%
System	8.6	136	0.06

Table 13
Radiological and Chemical Analysis
Eldon, Iowa Water Supply
September 13, 1974

Sampling Point	Gross Alpha pCi/l	Ra 226 pCi/l	Hard-ness mg/l	Total Solids mg/l	Alkalinity		pH	Iron		Ca mg/l	Mg mg/l	Na mg/l	Mn mg/l	Cl mg/l	SO4 mg/l
					P mg/l	T mg/l		Total mg/l	Sol mg/l						
Well #8 1901' 30 min	95	48	350	1243			7.5	2.0		82	36	270		160	
Well #8 1901' 6 hr	53	50	400	1228	0	252	7.5	1.9	1.9	82	37	280	0.01	160	490
Iron Filter Eff 1 hr	67	42	340	1245			7.75	0.10		82	37	260		160	
Iron Filter Eff 12 hr	74	44	380	1218	0	380	7.85	0.51	0.51	83	37	280	<0.01	160	490
*Softener #1 Eff 1 hr	7	1.9	12	1123			7.9	0.07		3.5	1.5	420		180	
Softener #1 Eff 20,000 gal	6.2	2.5	14	1295			7.9	0.80		2.9	1.4	430		180	
Softener #1 Eff 40,000 gal	5.6	1.3	8	1350	0	241	8.0	0.11	0.11	2.3	0.9	430	0.01	160	500
Softener #1 Eff 101,000 gal	11	1.8	6	1260			7.65	0.01		1.3	0.6	410		160	
Iron Filter Backwash 2 min	1540	1027	370	1703	0	246	7.6	230	230	94	38	280	0.86	170	500
Iron Filter Bakcwash 6 min	1270	254	260	1280			7.6	61		85	37	260		160	
Softener #1 Backwash 2 min	81	42	204	1258			7.5	7.8		47	24	330		160	
Softener #1 Backwash 10 min	47	18	74	1264			7.55	7.2		14	8.6	380		160	
Softener #1 Brine Rinse 10 min	670	400	5150	18420			6.9	0.18		1200	830	3000		8500	
Softener #1 Brine Rinse 20 min	3700	2800	21300	73178			6.4	0.30		5000	2600	9800		32000	
Softener #1 Brine Rinse 30 min	4000	3500	27000	88372	0	1580	6.4	0.54		6000	2600	14800	0.2	41000	1100
Softener #1 Brine Rinse 40 min	1800	1300	10800	55370			6.6	0.40		2800	1100	10400		24000	
Distribution System	22	8.6	136	1373			8.25	0.06		51	23	420		260	

Iron caps used on sample collection bottles
and some iron results may be in error

supply, and the various stages in treatment to indicate changes in other parameters. Additional mineral analyses are shown in Appendix A. Percentage removals of radium-226, iron and hardness are also shown on Figure 20.

Well

The 1,901 foot deep Jordan well pumped at a 200 gpm rate serving as the raw water supply has the highest radium content of the well samples in the study. Well samples collected at 30 minute and 6 hour pumping periods showed radium-226 values of 48 and 50 pCi/l respectively. Other chemical parameters showed little or no change during the pumping period. The well water hardness and sulfates averaged 375 mg/l and 160 mg/l respectively.

Iron Removal Filter

No samples were collected of the detention tank effluent because of the short seven minute detention time. The average radium-226 and iron concentrations of 49 pCi/l and 2.0 mg/l were reduced by passage through the iron removal filters to 43 pCi/l and 0.3 mg/l respectively. These values indicate radium and iron removals of 12 percent and 85% respectively through the iron removal filter.

Ion Exchange

Radiological and chemical analyses shown in Table 13 were collected at 20,000, 40,000 and 101,000 gallon intervals through the softening cycle. The softener did not reach the point of exhaustion at 101,000 gallons since it was believed at the time of the survey the design capacity was a lesser quantity. Additional samples could not be collected from the second softener due to lack of a sampling petcock.

Radium-226

Figure 20 shows that radium-226 concentrations were reduced from an average of 43 pCi/l to an average of 1.9 pCi/l following ion exchange for a removal of 96%. The maximum reduction was down to a radium-226 concentration of 1.3 pCi/l at 40,000 gallons through the softening cycle. Hardness removal was also near the maximum at this point.

Hardness

Total hardness was reduced from an average hardness of 375 mg/l to an average hardness of 10 mg/l by passage through the ion exchange softener for an average hardness removal of 97%. Hardness values during the softening cycle ranged from 6 to 14 mg/l.

Calcium and magnesium ions were reduced by the cation exchanger from average raw water values of 82 and 37 mg/l to average softened values of less than 4 and 1.3 mg/l respectively. Sodium increased from a raw water value of 270 mg/l to an average of 430 mg/l in the softened water. No other significant changes occurred in other chemical parameters.

ION EXCHANGE REGENERATION

Samples for radiological and chemical analyses were collected from softener discharges at various stages of the backwash, brine and rinse cycles. These values are shown in the data table 13. Table 14 includes the regeneration and water usage data for the complete cycle.

TABLE 14

Regeneration & Water Use Data

Cycle	Time	Pumping Rate	Water Quantity
Softening	22.4 hrs	75 gpm	101,000 gal
Backwash	22 min	90 gpm	2,000 gal
Brine	13 min	32 gpm	420 gal
Rinse	110 min	60 gpm	6,600 gal

Backwash

The ion exchange backwash was sampled at the two minute and 10 minute intervals during the backwash period of 22 minutes. The radium-226 content showed no increase during the backwash indicating no radium attached to or absorbed by the slight amount of suspended solids. The softener had not yet reached the exhaustion point at the time of backwash. An increase in iron content to 7.8 and 7.2 mg/l was noted in the backwash but the washwater was clear and the iron was not noticeable by visual means.

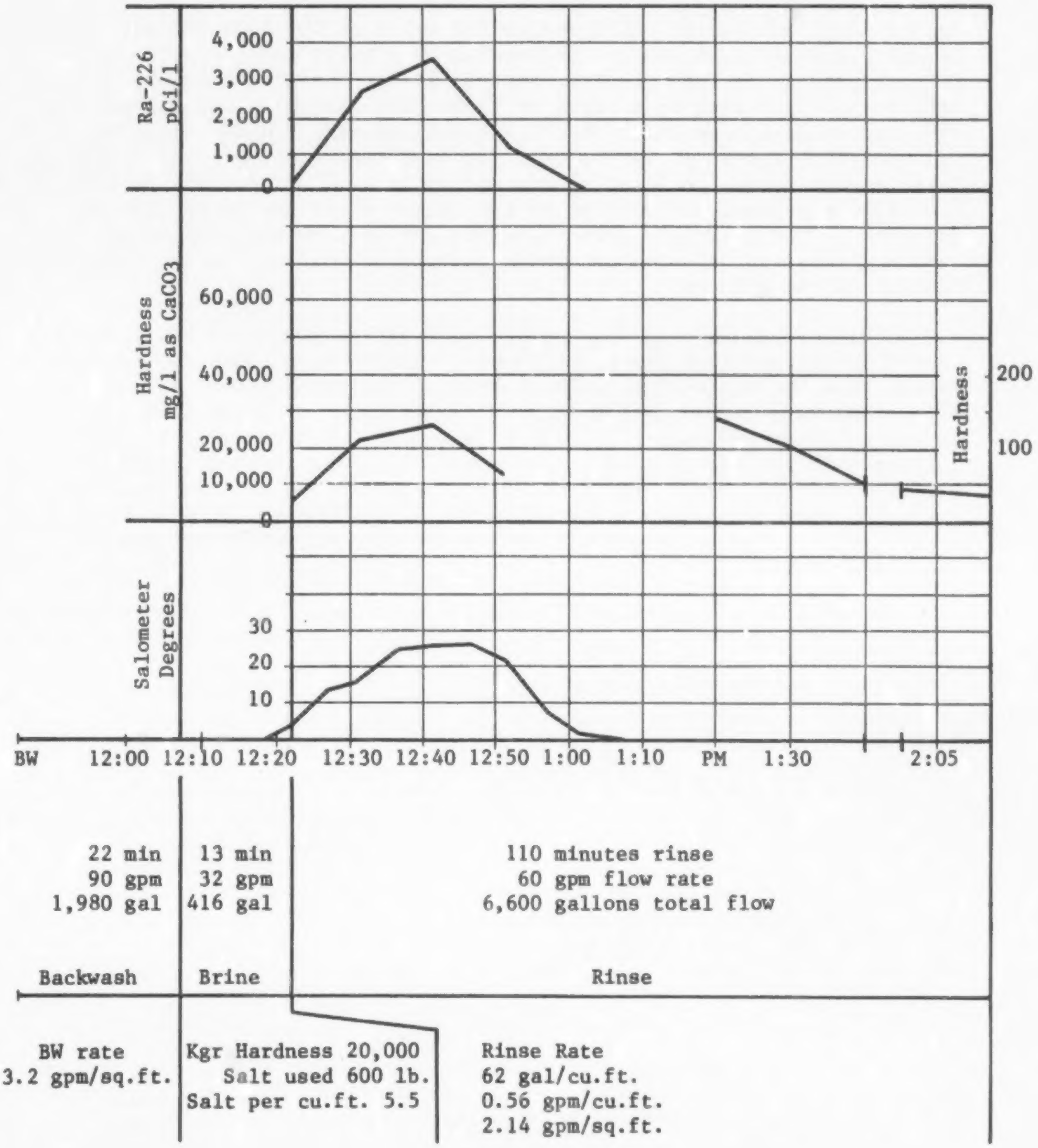
Brine Cycle

Saturated brine is pumped from a brine storage tank by an ejector with a capacity of approximately 30 gpm. During the downward brine cycle salometer degree readings were taken continuously to determine when the readings increased indicating chlorides of calcium and magnesium and the excess regenerant were passing to waste from the softener. Salometer readings were taken at five minute intervals and four samples for radiological and chemical analyses were collected at ten minute intervals to indicate changes during the brine and rinse cycle.

Figure 22 is a graph of the salometer degree readings (includes other ions than NaCl), hardness and radium-226 determinations on samples collected from the waste water during the brine-rinse cycle. Radium-226 concentrations in the brine rinse increased to a maximum of 3,500 pCi/l, hardness increased to 27,000 mg/l and the salometer degree reading increased to 24 percent. The total solids increased to a maximum of 88,400 mg/l, calcium to 6,000 mg/l, magnesium to 2,600 mg/l, sodium to 14,800 mg/l and chlorides to 41,000 mg/l.

FIGURE 22
Eldon, Iowa
September 13, 1974

No. 1 Zeolite Softener Brine & Rinse Cycle



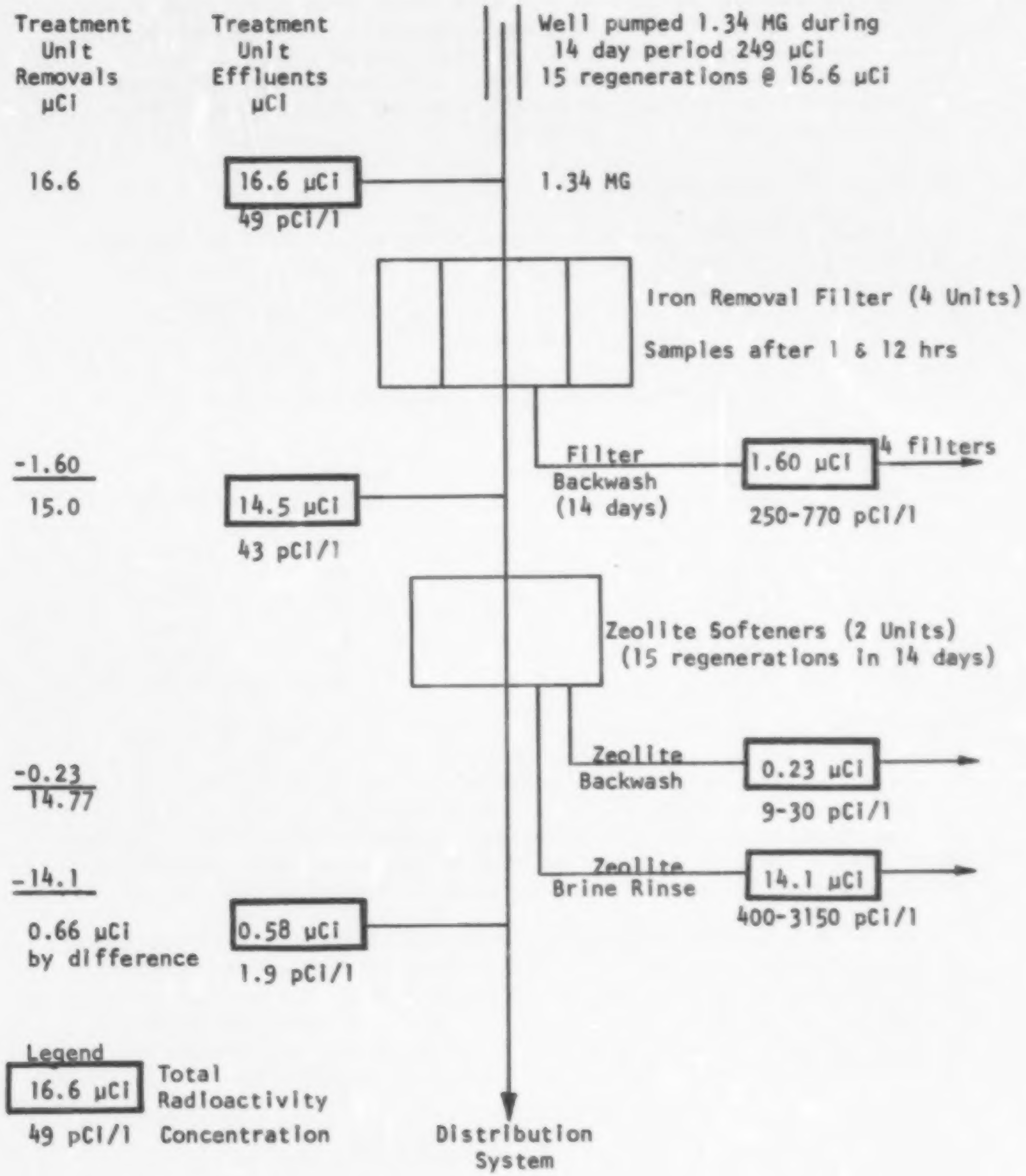
RADIUM-226 MATERIAL BALANCE

Figure 23 is a schematic drawing showing water treatment units and the radium-226 radioactivity and concentrations at various stages in the treatment process. Detailed radium computations are as shown in Appendix B.

Applying the average 49 pCi/l radium-226 value to the well pumpage of approximately 1.34 million gallons gives a total radioactivity of 249 µCi passing through the iron removal filter during the 14 day filter run. Dividing by a total of 15 zeolite softening and regeneration cycles of approximately 90,000 gallons each reduced the total radioactivity furnished by the well for each regeneration to 16.6 µCi. Likewise the composite total radioactivity of 25.2 µCi removal by the iron filter backwash is reduced by the factor of 15 cycles to 1.60 µCi for each softener cycle. This value subtracted from the well water radioactivity approximates the radioactivity of 14.5 µCi in the iron removal filter effluent.

Radioactivity removals in the zeolite softener backwash and brine rinse were 0.23 µCi and 14.1 µCi respectively. Subtracting these two removal values from the radium-226 radioactivity in the iron removal filter effluent leaves a difference of 0.66 µCi as compared with the 0.58 µCi in the softener effluent. This is a reasonably good material balance despite difficulties in securing accurate flow data in some stages of the treatment process extending over the two week period. An excellent reduction from an average of 49 pCi/l in the well water to an average of 1.9 pCi/l in the softener effluent indicates an average radium-226 reduction of 96%.

Figure 23
Ra-226 Distribution in Treatment Process
Eldon, Iowa
Iron Removal and Zeolite Softening


Treatment Unit Removals µCi
Treatment Unit Effluents µCi
Well pumped 1.34 MG during 14 day period 249 µCi
15 regenerations @ 16.6 µCi
16.6
16.6 µCi
49 pCi/l
1.34 MG
Iron Removal Filter (4 Units)
Samples after 1 & 12 hrs
Filter Backwash (14 days)
1.60 µCi
4 filters
250-770 pCi/l
-1.60
15.0
14.5 µCi
43 pCi/l
Zeolite Softeners (2 Units)
(15 regenerations in 14 days)
Zeolite Backwash
0.23 µCi
9-30 pCi/l
-0.23
14.77
Zeolite Brine Rinse
14.1 µCi
400-3150 pCi/l
-14.1
0.66 µCi by difference
0.58 µCi
1.9 pCi/l
Legend
16.6 µCi
Total Radioactivity
49 pCi/l
Concentration
Distribution System

SECTION 12.3
ESTHERVILLE

BACKGROUND DATA

Estherville is the county seat of Emmet County in northwest Iowa. Estherville with, a population of 8108 persons, is the largest city in Emmet County and is part of the Iowa Great Lakes recreational area. Emmet county is primarily agriculturally oriented and has shown a drop in population due to off-farm migration. Estherville's industries include beef, pork, and poultry processing plants; feed milling, packaged foods, egg processing, chemical fertilizer and concrete products.

EXISTING WATER FACILITIES

Estherville presently gets its public water supply from six Jordan aquifer wells ranging in depth from 750 to 780 feet. The wells are described in Table 15.

Table 15

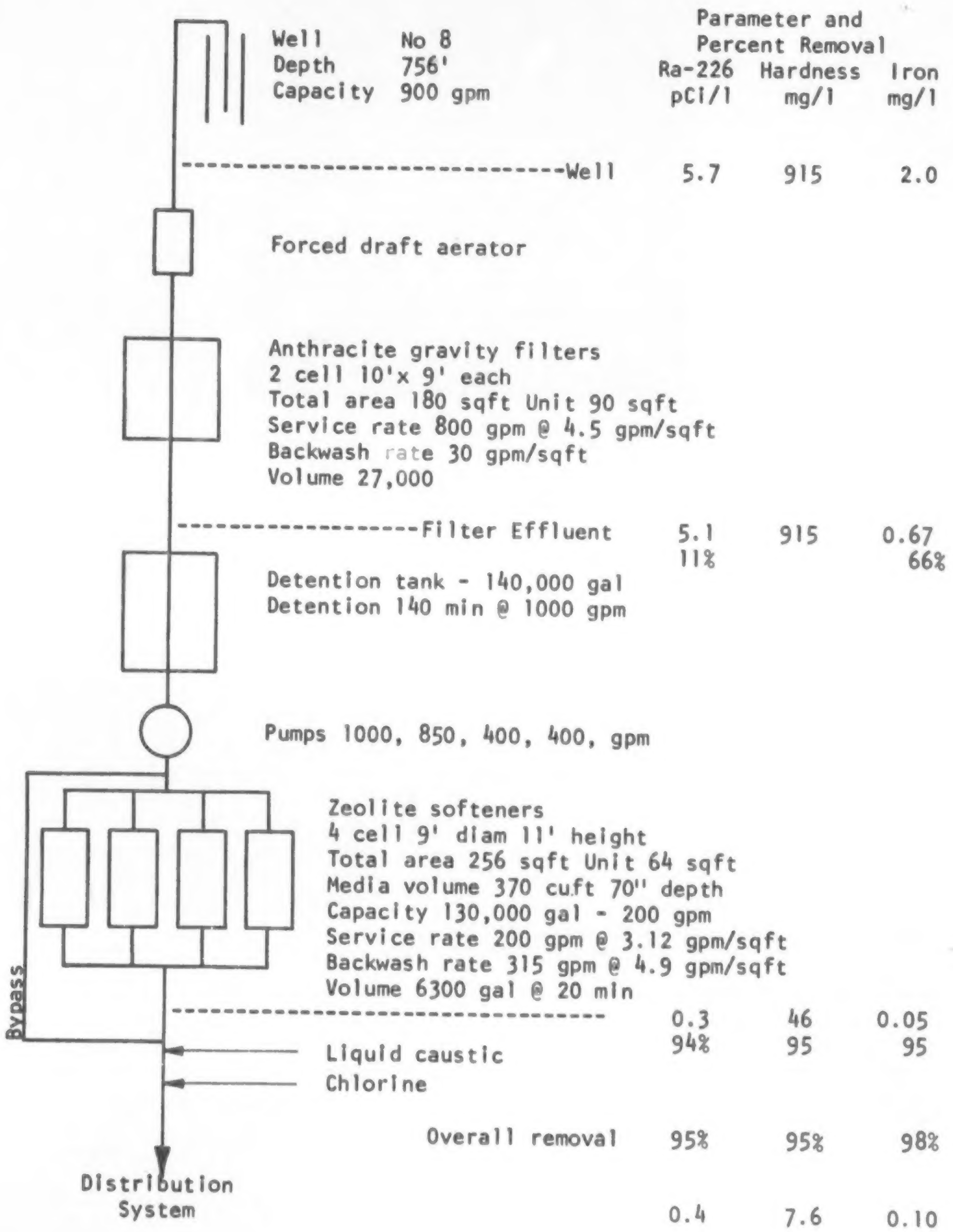
WATER SUPPLY WELLS - ESTHERVILLE

Well No.	Year Drilled	Depth	Capacity (gpm)	Approx. Pumping Rate (gpm)	Aquifer
4	1941	780	750	400	Jordan
6	1954	775	1,000	850	Jordan
7	1956	775	1,200	500	Jordan
8	1958	756	1,200	900	Jordan
9	1965	750	1,200	700	Jordan
10	1972	772	1,200	800	Jordan

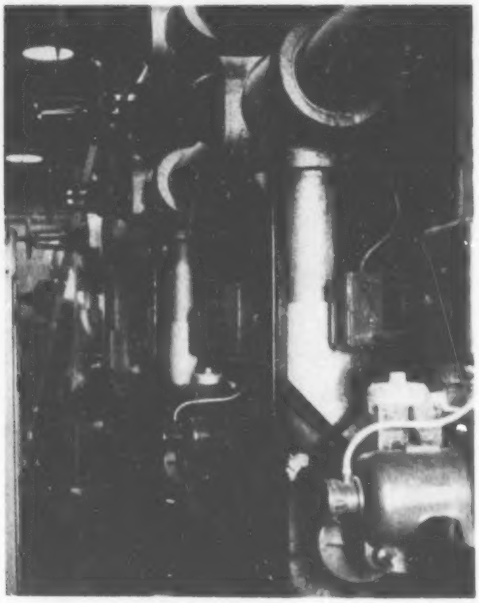
Estherville has two separate water systems, an industrial untreated water system and a treated water system. All wells can be connected to the raw water system with a separate elevated storage tank but only one well, No. 8, was being used during the survey period to serve as the raw water supply for the municipal treated water system. The raw water system has only six customers which includes large industrial users, such as the beef, pork, and poultry processing plants.

Figure 24 is a flow diagram of the Estherville ion exchange softening plant. Raw water from Well No. 8 is pumped through a forced draft aerator directly through gravity anthracite iron removal filters into a 140,000 gallon surface reservoir. High service pumps discharge through four pressure vertical ion exchange softeners (figure 25) at a normal rate of 800 gpm to the distribution system.

Figure 24
Flow Diagram
Estherville, Iowa - Population 8,108 (1970)
Gravity Iron Removal Filter and Zeolite Softener Plant
October 8, 1974


Well No 8
Depth 756'
Capacity 900 gpm
Well
Forced draft aerator
Anthracite gravity filters
2 cell 10'x 9' each
Total area 180 sqft Unit 90 sqft
Service rate 800 gpm @ 4.5 gpm/sqft
Backwash rate 30 gpm/sqft
Volume 27,000
Filter Effluent
Detention tank - 140,000 gal
Detention 140 min @ 1000 gpm
Pumps 1000, 850, 400, 400, gpm
Zeolite softeners
4 cell 9' diam 11' height
Total area 256 sqft Unit 64 sqft
Media volume 370 cu.ft 70" depth
Capacity 130,000 gal - 200 gpm
Service rate 200 gpm @ 3.12 gpm/sqft
Backwash rate 315 gpm @ 4.9 gpm/sqft
Volume 6300 gal @ 20 min
Bypass
Liquid caustic
Chlorine
Distribution System

	Parameter and Percent Removal		
	Ra-226 pCi/l	Hardness mg/l	Iron mg/l
Well	5.7	915	2.0
Filter Effluent	5.1 11%	915	0.67 66%
	0.3 94%	46 95	0.05 95
Overall removal	95%	95%	98%
	0.4	7.6	0.10



Ion Exchange Softeners
Figure 25

Unsoftened water is added to the softened ion exchange softener effluent to provide sufficient calcium carbonate for deposition of a protective coating on the water mains. Liquid caustic and liquid chlorine are also added to the plant effluent.

Iron filter backwash, softener backwash and spent brine rinse are discharged to a storm sewer with final discharge to the Des Moines River.

IRON FILTER AND ION EXCHANGE PERFORMANCE

Table 16 is a tabulation of the radiological and chemical analyses performed on samples collected from No. 8 deep well furnishing the raw water supply during the survey period and from various stages in the iron removal, softening and regeneration cycles. Additional mineral analyses are shown in Appendix A. Percentage removals of radium-226, iron and hardness are also shown on the plant flow diagram, Figure 24.

Table 16
Radiological and Chemical Analysis
Estherville, Iowa Water Supply
October 8, 9, & 10, 1974

Sampling Point	Gross Alpha pCi/l	Ra 226 pCi/l	Hard-ness mg/l	Total Solids mg/l	Alkalinity P mg/l	Alkalinity T mg/l	pH	Iron Total mg/l	Iron Sol mg/l	Ca mg/l	Mg mg/l	Na mg/l	Mn mg/l	Cl mg/l	SO_4 mg/l
Well #8 756' 30 min	10	6.2	915	1360			7.1	2.0		240	84	64		2.5	
Well #8 756' 6 hr	5.5	5.2	915	1350	0	367	7.1	1.6	1.6	240	83	59	0.24	3.0	670
Iron Filter Eff 8 hr	5.9	4.9	925	1359				0.71		240	84	57		8	
Iron Filter Eff 27 hr	6.3	5.3	915	1344			7.5	0.64		240	84	58		5.5	
Iron Filter Eff 30 day	16	8.1	915	1360	0	372	7.7	2.8	2.8	240	83	55	0.27	2	670
*Iron Filter Eff 7 day	8.6	3.0	883	1325	0	358	7.8	0.05		220	82				
*Iron Filter Eff 15 day	13	4.2	908	1358	0	394	7.7	0.17	0.7	230	82				
Iron Filter BW 5 min	4154	1980	1450	1399			7.25	1300		420	93	64		3	
Iron Filter BW Comp	227	165	1100	1375			7.4	320		290	86	58		3	
*Iron Filter BW 1-30' Comp	144	66						120							
Softener Inf	9	4.8	960	1361			7.3	0.27		240	84	57		1.5	
Softener Inf	13	4.9	915	1356			7.4	0.77		240	83	57		3	
Softener #3 Eff 1 hr	2.4	0.6	56	1385			7.55	0.21		17	6	430		19	
Softener #3 Eff 50%	3.3	0.1	36	1360	0	386	7.5	0.08		11	4.1	420	0.01	3	630
Softener #3 Eff 132,000 100%	2.3	0.4	185	1315			7.35	0.04		28	30	370		2	
Softener #3 Eff 142,000	3.9	0.8	840	1334			7.25	0.02		120	140	110		4	
Softener #4 Eff 25%	2.3	0.3	38	1357			7.5	0.17		10	[illegible]	440		5	
Softener #2 Eff 56,000	4.0	0.2	40	1359			7.45	0.08		18	5.0	450		11	
Combined Eff 6 hr	5.9	0.7	46	1360			7.45	0.09		13	3.9	440		11	
Combined Eff 10 hr	1.4	0.5	48	1370	0	396	7.6	0.10		13	3.8	420	0.01	9.5	630
Blended Eff 4 hr	7.0	0.4	76	1395			8.2	0.10		20	6.5	420		6	
Softener #3 BW 5 min	223	106	680	1354			7.3	25		150	73	200		6	
Softener #3 BW Comp	226	94	715	1367			7.3	17		170	75	150		3	
Softener #3 Rinse 5 min	160	80	70000	97962			6.2	1.0		15000	8500	1200		38000	
Softener #3 Rinse 10 min	470	320	63500	193000			5.9	0.98		19000	4200	24000		86300	
Softener #3 Rinse 15 min	128	52	10800	48900	0	546	6.9	0.34		3100	820	13000	0.78	26000	1400
Softener #3 Rinse 20 min	10	5.4	1620	9195			7.25	0.26		440	160	3000		5000	

*Samples collected January 30 - February 20, 1975

Well

The 750 ft. deep No. 8 well pumped at a 900 gpm rate is the shallowest Jordan sandstone well sampled during the project study. The well samples collected at 30 minute and 6 hour intervals showed a slight decrease in radium activity from 6.2 to 5.2 pCi/l after the longest pumping period. The hardness, total solids and other chemical parameters showed little or no significant change during the pumping period. Hardness in the well water averaged 915 mg/l, total solids 1355 mg/l and iron 1.8 mg/l.

Table 17 lists the concentrations and percentage removals of these pertinent radium and chemical constituents through the iron removal filter and softener units.

Table 17
Radium-226, Hardness and Iron Removals
Iron Removal-Zeolite Softener
Estherville, Iowa
October 8, 1974

	Ra-226		Hardness		Iron	
Sampling Point	pCi/l	Percent Removal	mg/l	Percent Removal	mg/l	Percent Removal
Well Supply	5.7		915		2.0	
Iron Filter Effluent	5.1	11	915		0.38	81
Softener Effluent	0.3	94	46	95	0.05	87
Overall Removal	0.3	95	46	95	0.05	97
Blended Effluent	0.4		76		0.10	
January 30-February 20, 1975 Composites						
Iron Filter Effluent						
7th day	3.0	47			0.05	97
15th day	4.2	26			0.17	91

Iron Removal Filter

The iron removal filter showed considerable variation in removals of radium-226 and iron during two filter runs sampled during the first survey in October, 1974 and the recheck survey during February, 1975. The radium-226 was reduced from 6.2 and 5.5 pCi/l values to 4.9 and 5.3 pCi/l levels in the iron filter effluent at 8 hours and 27 hours through the filter run during the October, 1974 survey. The radium-226 content of the iron removal filter effluent at the end of the 30 day filter run was 8.1 pCi/l or an actual increase in the effluent as compared with the influent levels. Likewise the iron content of the iron removal filter effluent on the 30th day of the filter run increased to 2.8 mg/l indicating possible sloughing of iron from the filter.

The filter run of the iron removal filter had been increased about a week to permit the survey sampling and filter backwash at a time which would permit a visit by personnel of the U.S. Environmental Protection Agency. Subsequent sampling of the iron removal filter effluent with a shorter filter run indicated better radium and iron removal as shown by Table 17.

The samples collected during the February, 1975 survey showed radium-226 values of 3.0 and 4.2 pCi/l in the 7th day and 15th day composite samples of the iron removal filter effluent. Disregarding the 30 day filter effluent value, the radium-226 removal through the iron removal filter using average well supply values and filter effluent values was 14% on the October survey and 47% and 26% on the two composites in February.

During the February, 1975 survey, iron removal filter samples were collected at two day intervals for iron analysis during the 21 day filter run prior to backwash. These values are shown graphically in figure 26. The graph shows iron content in the filter effluent to be generally in the 0.05 to 0.3 mg/l range as contrasted with the 0.71 to 0.64 mg/l values found in the earlier survey in October, 1974. These higher values were found following the longer 30 day filter run indicating lower iron removal efficiency.

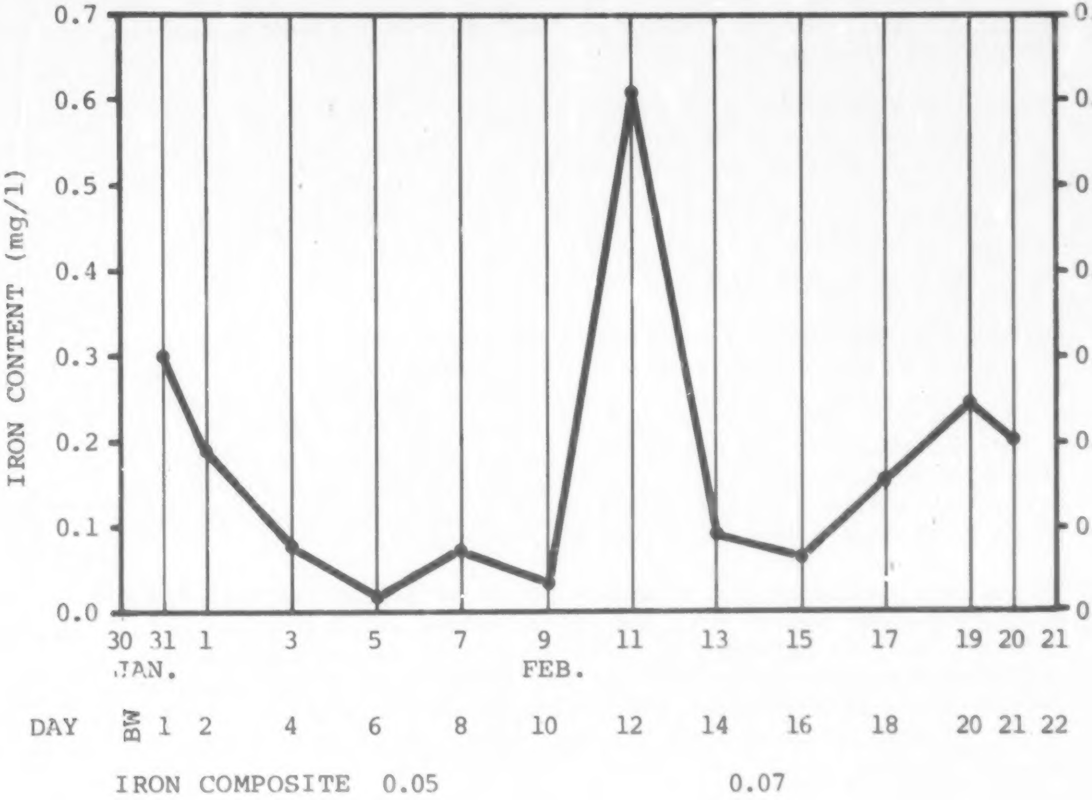
These results indicate some amount of radium-226 activity is removed in a concurrent manner with the ferric oxides and hydroxides or possibly ferrous carbonates. Relatively poor radium removal is associated with the poor iron removal on the iron filter that had been previously overloaded whereas better radium removal occurred with the much improved iron removal during the February survey.

There was no visible color or turbidity in the iron removal filter effluent or the softener influent samples reported in table 16. The softener influent analyses showed iron determinations of 0.27 and 0.77 mg/l which are similar to the filter effluent samples. Likewise the backwash water from the softener showed no visible color or turbidity indicating little suspended matter even though an iron content of 17 mg/l of iron was present.

The removal of total iron through the iron filter using the average values of the well supply and the iron removal filter effluent during the two sampling periods was 81 percent. The percentage of iron removal and radium removal improved to 97% and 91% when the filter effluent composite values of the February, 1975 survey were used.

FIGURE 26

TOTAL IRON ANALYSIS
IRON REMOVAL FILTER RUN
16,854,000 GALLONS
JANUARY 30 TO FEBRUARY 20, 1975



Ion Exchanger

Radiological and chemical analyses shown in Table 16 were collected at the 1 hour, 50%, 100% (132,000 gal.) and 110% (142,000 gal.) intervals through the softening cycle of the #3 softener. Additional samples were also collected from softeners #2 and 4, from the combined effluent and from the blended effluent containing about six percent unsoftened water.

Radium-226

The radium-226 concentration was reduced from the 5.7 to 5.3 pCi/l range to a 0.1 range of values following ion exchange softening. The low value of 0.1 pCi/l was recorded at 50% through the softening run with an average radium-226 removal of 94% through the ion exchange unit and 95% overall as shown in Table 17.

Hardness

Total hardness was reduced from 915 mg/l to an average hardness of 46 mg/l through the ion exchange softener for an average hardness reduction of 95%. Hardness values during the softening cycle on six samples from the various filters ranged from 38 to 56 mg/l. These hardness values are somewhat higher than expected and may indicate some loss of softening capacity over the 20 years of service of the softener.

The data indicates a slight decrease in hardness leakage after regeneration with a rapid rise in hardness to 185 mg/l compared to a radium-226 value of 0.4 pCi/l at the end of the normal softening cycle as the exchanger media was approaching exhaustion. The #3 softener was deliberately run 10,000 gallons past its normal regeneration time to determine the radium removal as the exchanger media was nearing complete exhaustion. At this point the hardness had risen to 840 mg/l (raw water hardness 915/mg/l) as compared with a radium-226 content of 0.8 pCi/l (raw water average 5.7 pCi/l). The data confirms other studies indicating radium removal continuing after hardness removal capacity was exhausted.

Calcium and magnesium ions were reduced by the cation cation ion exchanger from average raw water values of 240 and 84 mg/l to 11 and 4 mg/l respectively at the 50% softening cycle point. There was a significant increase in sodium content from an average of 60 mg/l in the well water to 430 mg/l in the softened water due to exchange of the sodium for the calcium and magnesium ions.

Approximately 6 percent unsoftened water was bypassed around the softener and blended with the finished water being pumped to the distribution system. This blended effluent had a radium-226 concentration of 0.4 pCi/l, a hardness content of 76 mg/l and an iron content of 0.1 mg/l as shown in Table 16.

ION EXCHANGE REGENERATION

Samples for radiological and chemical analyses were collected from softener discharges at various stages of the backwash, brine and rinse cycles during regeneration. These values are also shown in Table 16. Table 18 shows the regeneration and water usage data for the complete cycle.

These rates and quantities are shown in the plant flow diagram, Figure 24 and Figure 27 showing the brine and rinse cycle.

Table 18
Regeneration and Water Use Data

Cycle	Time	Pumping Rate	Water Quantity
Softening	10.8 hrs.	200 gpm	130,000 gal
Backwash	10 min.	315 gpm	3,150 gal
Brine	22 min.	74 gpm	1,630 gal
Rinse	37 min.	247 gpm	9,140 gal
Total			144,000 gal

Backwash

The ion exchanger backwash was sampled by a grab sample at 5 minutes and by a composite of 5 samples collected over the 10 minute backwash period. The radium-226 concentration in the backwash composite increased to 94 pCi/l and the iron content increased to 17 gpm although no suspended solids were visible in the effluent. These analyses may indicate some radium is removed by filtration or adsorption even though suspended solids were not apparent by visual means.

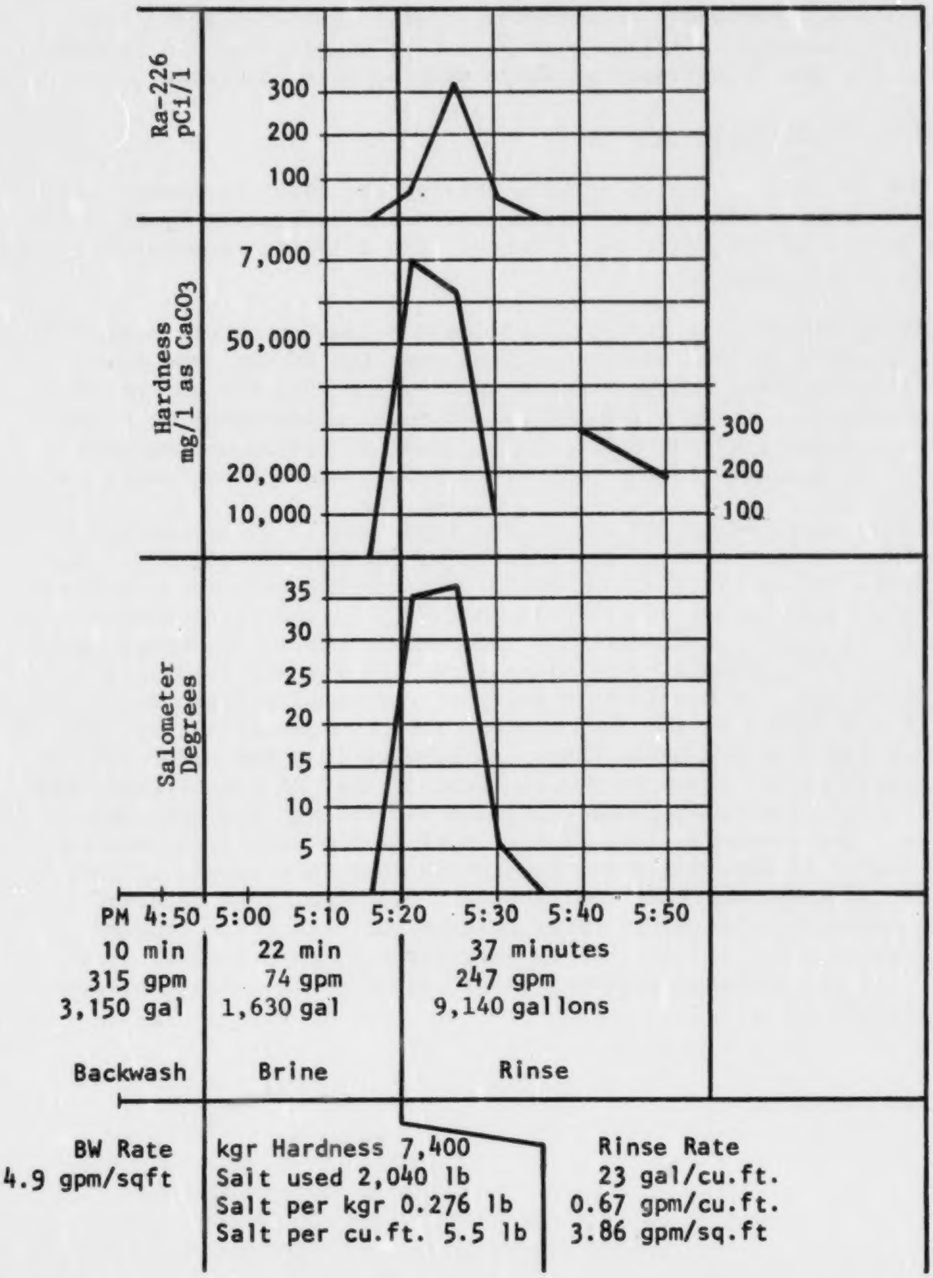
Brine and Rinse Cycles

Saturated brine is pumped at a rate of 42 gpm from the salt storage tank, diluted by 32 gpm of water from an injector for a total of 74 gpm for the 22 minute brine cycle. Salometer degree readings were taken continuously to determine when the salometer readings increased indicating chlorides of calcium and magnesium and the excess regenerant salt were passing to waste from the softener. Salometer degree readings were then taken at 5 minute intervals along with samples for radiological and chemical analyses at these intervals.

Figure 27 is a graph of the salometer degree readings (includes other ions), hardness and radium-226 determinations of the four samples collected during the brine cycle. Sampling extended into the rinse cycle discharge period. Radium concentration increased to a maximum of 320 pCi/l, hardness to 70,000 mg/l and the salometer degree reading 37 percent during the rinse cycle. Likewise, total solids increased to a maximum of 193,000 mg/l, calcium to 19,000 mg/l, magnesium to 42,000 mg/l, sodium to 24,000 mg/l and chlorides to 86,300 mg/l.

FIGURE 27
Estherville, Iowa
October 18, 1974

No. 1 Zeolite Softener Brine & Rinse Cycle



A graph of salometer degree readings at 5 minute intervals from the Nos. 1 and 4 softeners indicated similar salometer curves. The maximum salometer readings were 53 and 40 compared with a reading of 37 for the #3 softener on which samples were collected.

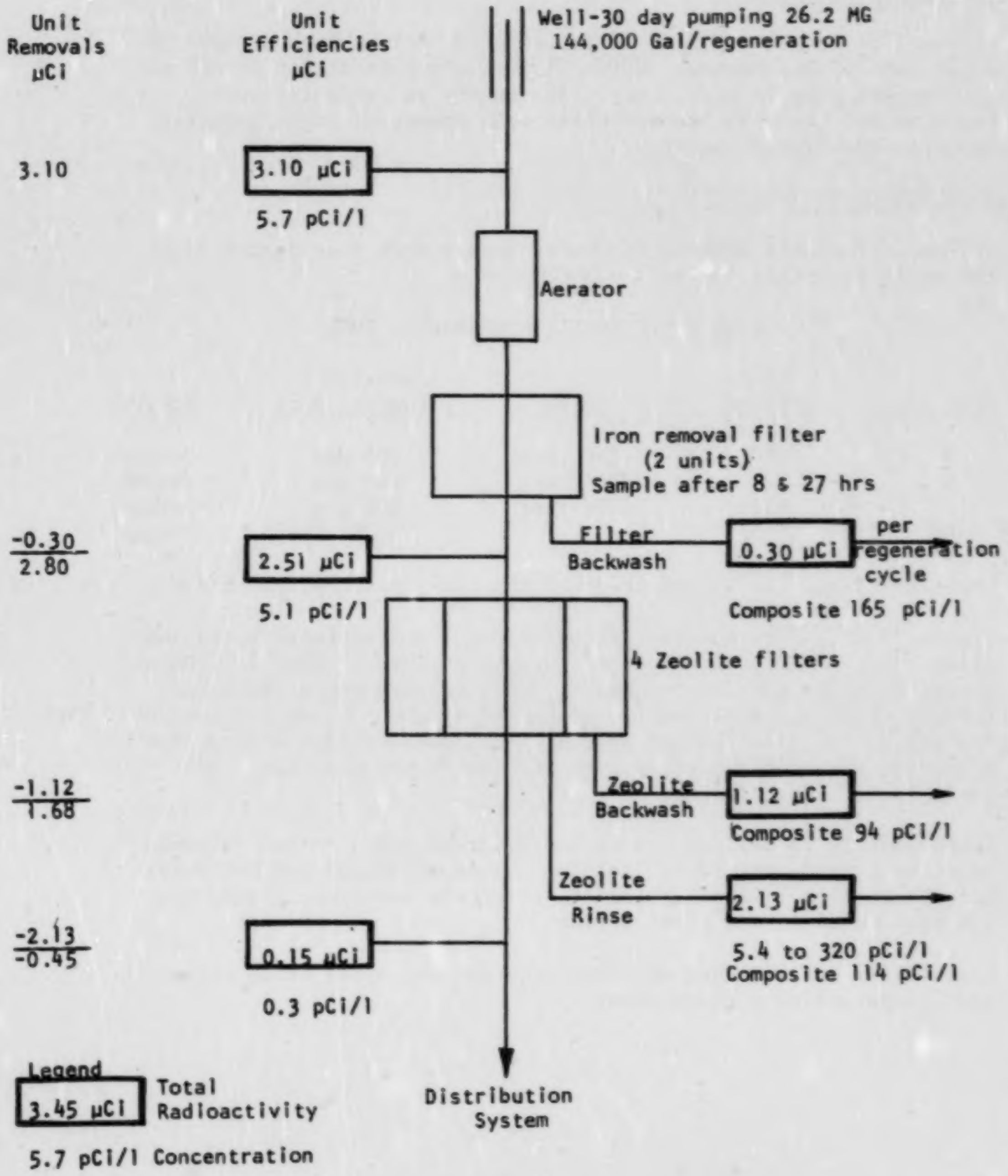
RADIUM-226 MATERIAL BALANCE

Figure 28 is a schematic drawing showing the water treatment units and the radium-226 concentrations and total radioactivity at various stages in the treatment process. The detailed computations are shown in Appendix B.

Applying the average 5.7 pCi/l radium-226 concentration value to the well pumpage of 26.2 million gallons over the 30 day iron filter run gives a total radium-226 radioactivity of 565 µCi in the well water pumped. Using a 144,000 gallon total water usage in a complete softening regeneration cycle gives 182 cycles during this period or 3.10 µCi in the well water during a softener cycle.

The composite radium content in the iron removal filter backwash was 54 µCi which reduced to a concentration of 0.30 pCi/l for each softener cycle. This value subtracted from the well water radioactivity should have equalled the activity in the iron removal filter effluent. Radioactivity removals in the ion exchange backwash and ion exchange brine rinse were 1.12 µCi and 2.13 µCi respectively. It should be noted that the total radioactivity level reductions by the iron removal filter backwash and ion exchange backwash and brine rinse are greater than the reduction in radioactivity as shown in the zeolite softener effluent. Thus there was a poor material balance of radium-226 through the treatment units. The unusually long iron removal filter run of 30 days and difficulty in securing a representative composite sample of this filter effluent may have contributed to difficulty in securing a good material balance. However an excellent reduction from an average of 5.7 pCi/l in the raw well water to an average of 0.3 pCi/l in the softener effluent was attained as an average radium-226 reduction of 95%.

Figure 28
Ra-226 Distribution in Treatment Process
Estherville, Iowa
Iron Removal and Zeolite Softener Plant


Unit Removals µCi
Unit Efficiencies µCi
Well-30 day pumping 26.2 MG
144,000 Gal/regeneration
3.10
3.10 µCi
5.7 pCi/l
Aerator
Iron removal filter
(2 units)
Sample after 8 & 27 hrs
-0.30
2.80
2.51 µCi
5.1 pCi/l
Filter
Backwash
0.30 µCi
per regeneration cycle
Composite 165 pCi/l
4 Zeolite filters
-1.12
1.68
Zeolite
Backwash
1.12 µCi
Composite 94 pCi/l
Zeolite
Rinse
2.13 µCi
5.4 to 320 pCi/l
Composite 114 pCi/l
-2.13
-0.45
0.15 µCi
0.3 pCi/l
Distribution System
Legend
3.45 µCi
Total Radioactivity
5.7 pCi/l Concentration

SECTION 12.4

GRINNELL

BACKGROUND INFORMATION

Grinnell is the county seat of Poweshiek County in Central Iowa,50 miles east of Des Moines. Grinnell,with a population of 8,402 is the largest city in the county. The county is agriculturally oriented and the city has a considerable amount of light industry and agri-associated industry.

EXISTING WATER FACILITIES

Grinnell presently derives its water supply from four Jordan aquifer wells described in the following table.

WELL WATER SUPPLY - GRINNELL, IOWA

Well No.	Year Drilled	Depth	Aproximate Pumping Rate	Aquifer
5	1920	2,250 feet	500 gpm	Jordan
6	1926	2,550 feet	460 gpm	Jordan
7	1955	2,500 feet	690 gpm	Jordan
8*	1974			Jordan

*Well No. 8 was not in operation at the time of the plant study.

Figure 29 is a flow diagram of the Grinnell ion exchange softening plant. Raw well water is pumped through an aerator into a 1,000,000 gallon concrete surface reservoir. High service pumps discharge through three vertical zeolite softeners (figure 30) at a normal unit rate of 330 gpm to the distribution system. Additional design information regarding the iron removal filter and ion exchange softener is given in the flow diagram.

Approximately 25 percent unsoftened water is added to the softened water to provide sufficient calcium carbonate deposition for water main protection. Liquid chlorine, phosphate and caustic soda ash are also added to the plant effluent.

Iron filter backwash and softener backwash and spent brine rinse are discharged to a storm sewer.

Figure 29
Flow Diagram
Grinnell, Iowa - Population 8,402 (1970)
Aeration and Zeolite Softener Plant

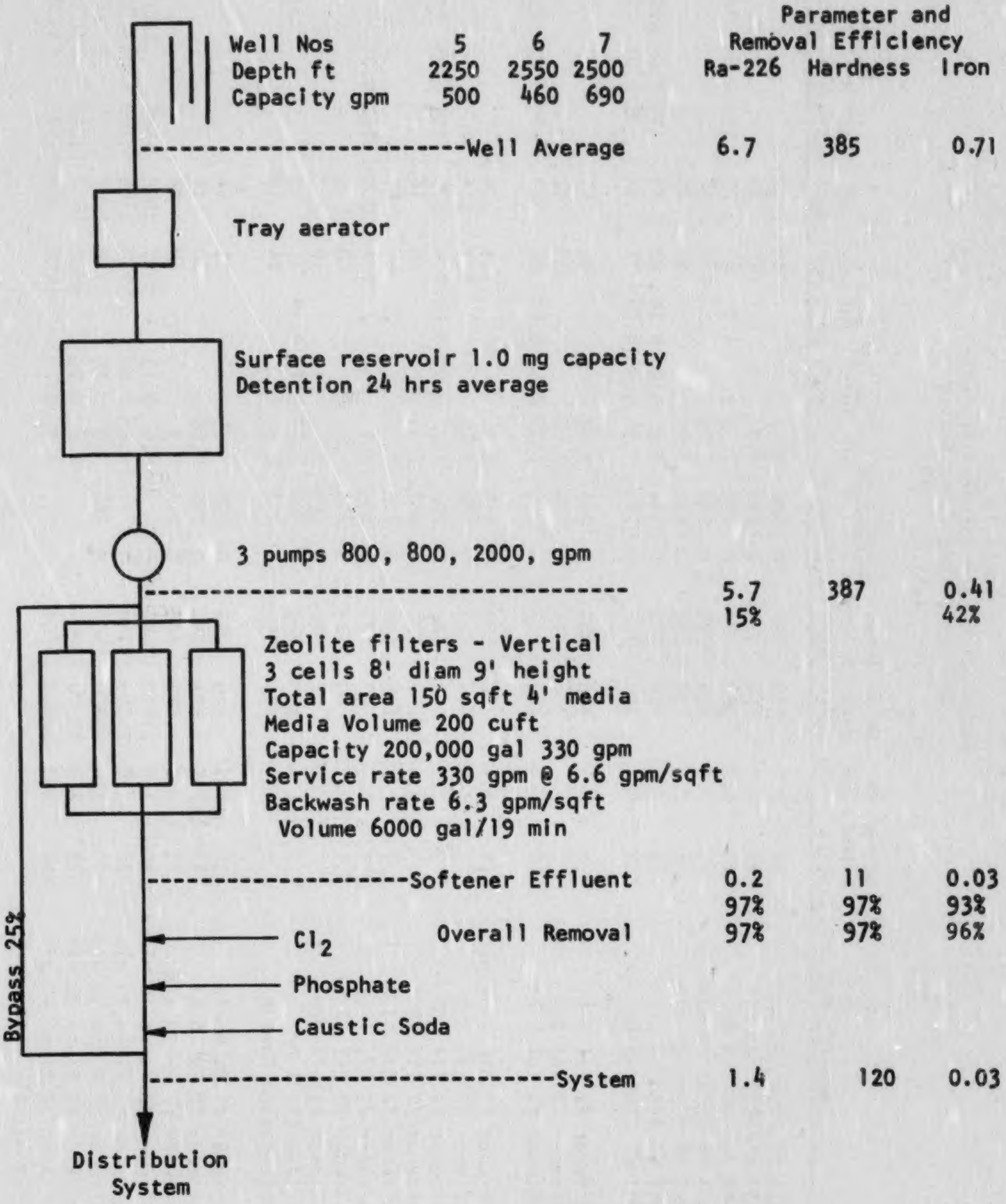

Parameter and
Removal Efficiency
Well Nos 5 6 7
Depth ft 2250 2550 2500
Capacity gpm 500 460 690
Ra-226 Hardness Iron
Well Average 6.7 385 0.71
Tray aerator
Surface reservoir 1.0 mg capacity
Detention 24 hrs average
3 pumps 800, 800, 2000, gpm
5.7 387 0.41
15% 42%
Zeolite filters - Vertical
3 cells 8' diam 9' height
Total area 150 sqft 4' media
Media Volume 200 cuft
Capacity 200,000 gal 330 gpm
Service rate 330 gpm @ 6.6 gpm/sqft
Backwash rate 6.3 gpm/sqft
Volume 6000 gal/19 min
Softener Effluent 0.2 11 0.03
97% 97% 93%
Overall Removal 97% 97% 96%
Bypass 25%
Cl2
Phosphate
Caustic Soda
System 1.4 120 0.03
Distribution
System

Table 19
Radiological and Chemical Analysis
Grinnell, Iowa Water Supply
July 8, 1974

Sampling Point	Gross Alpha pCi/l	Ra 226 pCi/l	Hard-ness mg/l	Total Solids mg/l	Alkalinity P mg/l	Alkalinity T mg/l	pH	Iron Total mg/l	Iron Sol mg/l	Ca mg/l	Mg mg/l	Na mg/l	Mn mg/l	Cl mg/l	SO4 mg/l
Well #5 2250' 10 min	10	7.1	368	764	0	306	7.35			83	42				280
Well #5 2250' 30 min	12	6.1	366	761	0	298	7.3			82	42				290
Well #5 2250' 4 hr	14	6.2	368	784	0	298	7.35	1.1	1.1	82	43	110	0.01	18	320
Well #6 2550' 10 min	12	7.3	655	1791	0	264	7.25			180	58				910
Well #6 2550' 30 min	16	7.6	410	888	0	316	7.05			98	45				370
Well #6 2550' 4 hr	23	7.2	420	922	0	334	7.3	0.26	0.26	98	46	130	0.01	24	380
Well #7 2500' 3 hr	5.4	4.1	368	742	0	263	7.3	0.76	0.76	82	44	95	0.01	16	290
Softener #2 Inf 1 hr	9.1	5.8	388	846	0	294	7.65			90	42				310
Softener #2 Inf Dup			388	814	0	294	7.55			89	42				320
Softener #2 Inf 4 hr	12	5.6	384	822	0	290	7.55	0.41	0.41	88	44	120	0.01	22	340
Softener #2 Eff 10 min	1.1	0.3	12	885	0	315	8.2			3.3	1.4				310
Softener #2 Eff 25%	0.3	0.1	16	830	0	294	7.45			1.3	0.3				310
Softener #2 Eff 50%	1.7	0.2	6	860	0	292	7.7	0.03	0.03	2.4	0.5	290	0.01	21	330
Softener #2 Eff 100%	0.3	0.9	106	824	0	292	7.3			18	16				310
Softener #2 Eff 110%	5.3	1.7	282	794	0	293	7.3			48	42				310
Softener #3 Eff 1 hr	Nil	0.2	10	835	0	295	7.7			2.4	0.9	260	0.01		310
Softener #1 Eff 12 hr	3.1	0.7	40	823	0	298	7.4			10	5				310
Softener #1 Eff Dup			48	822	0	294	7.4			10	5.2				300
Blended Eff 1 hr	2.5	1.4	100	880	17	328	8.65	0.14	0.14	21	11			21	330
Distribution System	1.5	1.4	120	852	18	330	8.6			26	15				310
Softener #2 BW 6 min	34	18.7	375	939	0	290	7.15			93	44				320
Softener #2 BW 10 min	30	12.5	374	851	0	296	7.25			80	39				320
Softener #2 BW 15 min	12	6.0	224	825	0	294	7.3			69	34				320
*Softener #2 Rinse 10 min	330	210	21400	17800			6.6	0.13		3900	2800	1980		16000	
*Softener #2 Rinse 20 min	520	320	24000	59700			6.65	0.20		5300	2800	8200		27500	
*Softener #2 Rinse 30 min	470	290	19800	56400	0	264	7.0	0.25		5120	1700	11000		32000	900
*Softener #2 Rinse 35 min	620	260	19500	70000			6.8	0.23		4800	1800	13000		27000	
*Softener #2 Rinse 40 min	440	220	12640	60000			7.0	0.23		3500	940	15400		13500	

*October 24, 1974

ION EXCHANGE PERFORMANCE

Table 19 is a tabulation of the radiological and chemical analyses performed on samples collected from the raw water supply and from the various stages of aeration, sedimentation, softening and regeneration cycles. Additional mineral analyses are shown in Appendix A. Percentage removals of radium-226, iron and hardness are also shown on the plant flow diagram, figure 29.

Well

The three Jordan formation wells drilled to depths of 2250 to 2550 feet and pumped at 460 to 960 gpm rates were sampled at various pumping times to indicate possible changes during the survey period. Variations occurred in the radium-226 concentrations during the 10 minute, 30 minute, and 4 hour sampling times on samples collected from wells 5 and 6. The four hour pumping period samples on these wells showed radium concentrations of 6.2 and 7.2 pCi/l compared with a 4.1 pCi/l concentrations on well #7 at 3.2 hour pumping period. A radium-226 value on a new well reported in April, 1975 showed a somewhat higher 8.1 pCi/l radium concentration. The hardness, total solids and other chemical parameters showed some variation between wells and pumping times. Considering all factors the following average well water values were used: radium-226 concentrations 6.7 pCi/l, hardness 385 mg/l, total solids 817 mg/l and iron 0.71 mg/l.

Aeration Sedimentation

Wells are pumped to a tray aerator located on top of a million gallon capacity,covered concrete surface reservoir. The theoretical detention time of 24 hours reduced the average iron content of 0.71 mg/l in the three well waters (assuming equal flows) to 0.41 mg/l in the influent pumped to the softeners for an iron removal of 42%. The variations in the radiological and mineral characteristics of the wells, differences in well pumping rates, reservoir levels and other factors make it difficul to arrive at a firm expected removal of iron and radium. However the reduction indicates that some amount of radium activity is removed by adsorption and sedimentation with ferric oxides and hydroxides as well as ferrous carbonate.

Ion Exchange

Radiological and chemical analyses shown in table 19 were collected at ten minutes (3300 gal), 25%, 50%, 100%, (200,000 gal), and 100% intervals through the softening or service cycle of the No. 2

softener. Additional samples were collected from softeners No. 1 and No. 3 to verify results. A sample was also collected of the blended effluent from the plant containing about 25 percent unsoftened water.

Radium-226

The radium-226 concentration was reduced from an average 5.7 pCi/l in the softener influent to an average 0.2 pCi/l range following ion exchange softening for a radium removal of 96% due to ion exchange. The data in table 19 indicates a radium increase from a low of 0.1 pCi/l at the 25% point in the softener run to 0.9 at the 100% point (200,000 gallons) when the softener is considered at the point of exhaustion (106 mg/l hardness) and is normally regenerated. The softener was deliberately run to the 110% point (220,000 gallons) past normal regeneration and the radium-226 value increased to 1.7 pCi/l. Better radium removal (1.7 pCi/l) was being accomplished than hardness removal (282 mg/l) indicating radium removal continuing after hardness removal capacity was exhausted.

Hardness

Total hardness was reduced from an average hardness of 387 mg/l in the softener influent to an average hardness of 11 mg/l through the ion exchange process for a hardness reduction of 97%. Hardness values during the softening cycle on four samples from various filters ranged from 6 to 16 mg/l.

The data in table 19 indicates rapid rise to 106 mg/l (raw water hardness 387 mg/l) of hardness at the end of the normal softening cycle which compares to the radium-226 concentration rise to 0.9 pCi/l. The hardness increased to 282 mg/l at the 110% point past the normal regeneration time.

Calcium and magnesium ions were reduced by the cation exchanger from an average raw water value of 88 and 44 mg/l to 3 and 1 mg/l respectively in the normal softening range. During the exchange cycle no significant changes occurred in concentration of total solids, alkalinity or sulfates. There was a significant increase in sodium from an average 110 mg/l to 275 mg/l in the softened water due to exchange of the sodium for the calcium and magnesium ions.

Approximately 25 percent unsoftened water was bypassed around the softener and blended with the finished water being pumped to the finished distribution system. This blended effluent had a radium-226 concentration of 1.4 pCi/l, a hardness content of 100 mg/l and an iron content of 0.14 mg/l as shown in table 19.

Ion Exchange Softener
Figure 30

ION EXCHANGE REGENERATION

Samples for radiological and chemical analyses were collected from softener discharges at various stages of the backwash, brine and rinse cycles. These values are also shown in table 19. Table 20 lists the regeneration stages and water usage data.

Table 20
Regeneration and Water Use Data

Cycle	Time	Rate	Water Quantity
Softening	11 hours	150 gpm	200,000 gal.
Backwash	22 minutes	320 gpm	7,000 gal.
Brine	32 minutes	90 gpm	2,900 gal.
Rinse	60 minutes	117 gpm	7,000 gal.

These rates and quantities are also shown in the plant flow diagram, figure 29.

Backwash

The ion exchanger backwash was sampled at the 6, 10 and 15 minute intervals through the 22 minute backwash to determine changes in the radiological and chemical analyses during the backwash (table

19). The initial 6 minute radium-226 value was 18.7 pCi/l with a decrease to 10 pCi/l at the 10 minute interval and to 6.0 pCi/l at the 15 minute interval which is the approximate raw water radium concentration.

The ion exchanger backwash was highly rust or yellow colored but with little visible suspended solids. Unfortunately no iron analyses were performed on these samples. These radium analyses do indicate that some radium is removed by filtration or absorption of radium by the iron oxides, hydroxides or carbonates.

Rinse Cycle

Saturated brine is pumped by an ejector from a saturated brine storage tank for the 32 minute brine cycle. Salometer degree readings were taken continuously to determine when the salometer reading (indicating specific gravity) increased, indicating chlorides of calcium and magnesium and the excess regenerant salt were passing from the softener. Salometer readings were then taken at 5 minute intervals and sampled for radiological and chemical analyses at 10 minute intervals to indicate changes during the brine-rinse cycle.

Figure 31 is a graph of the salometer degree readings (includes other ions), hardness and radium-226 determinations of the five samples collected during the brine cycle. Sampling was extended into the rinse cycle discharge period. Radium-226 concentrations in the brine rinse increased to a maximum of 320 pCi/l, hardness increased to 19,800 mg/l and the salometer reading rose to 17 percent. Total solids increased to a maximum of 59,700 mg/l, calcium to 5,300 mg/l, magnesium to 2,800 mg/l, sodium to 15,400 mg/l and chloride to 32,000 mg/l.

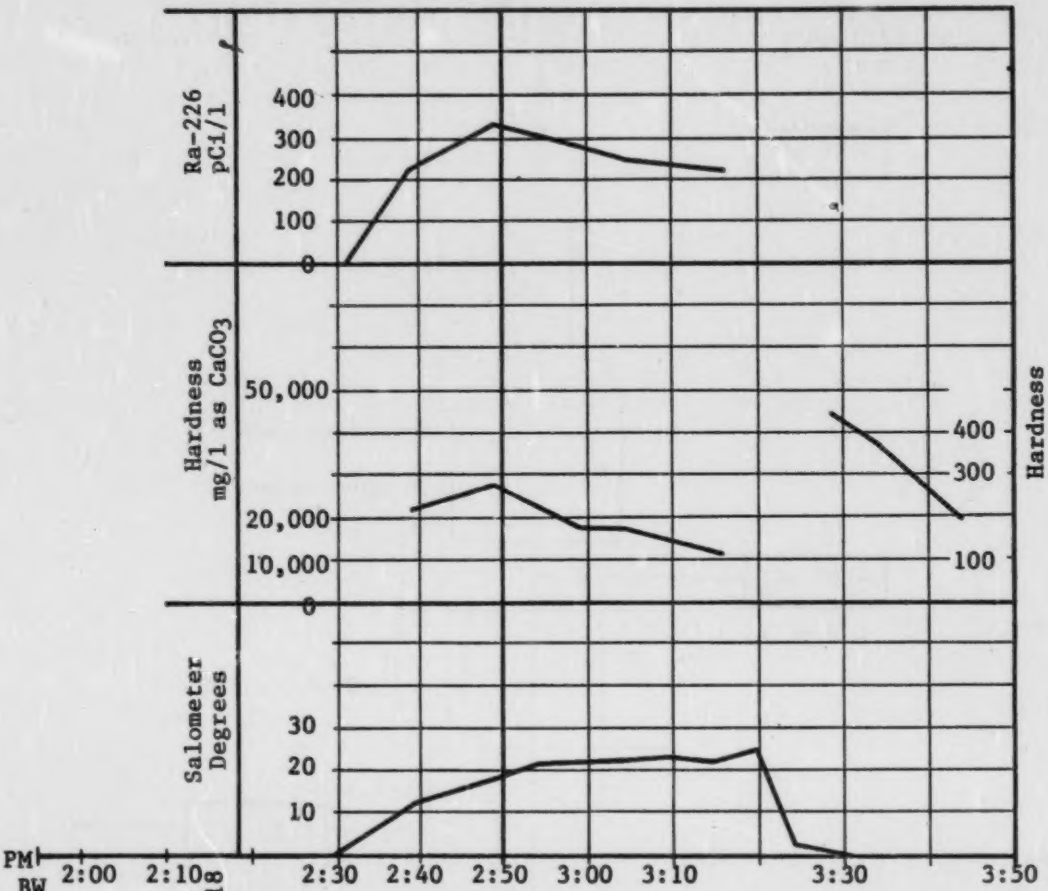
RADIUM-226 MATERIAL BALANCE

Figure 32 is a schematic drawing showing water treatment units and the radium-226 radioactivity at various stages in the treatment process. Detailed computations are shown in Appendix B.

Applying the average 6.7 pCi/l concentration value to the well pumpage of 213,000 gallons (including waste backwash and brine rinse) for a complete softener service and regenerant cycle gives a total radium radioactivity of 5.46 μCi in the well pumpage for the complete cycle. Aeration settling in the 1,000,000 gallon (24 hour detention) ground storage tank reduced the radium-226 concentration to 5.7 pCi/l for a total radioactivity of 4.66 μCi.

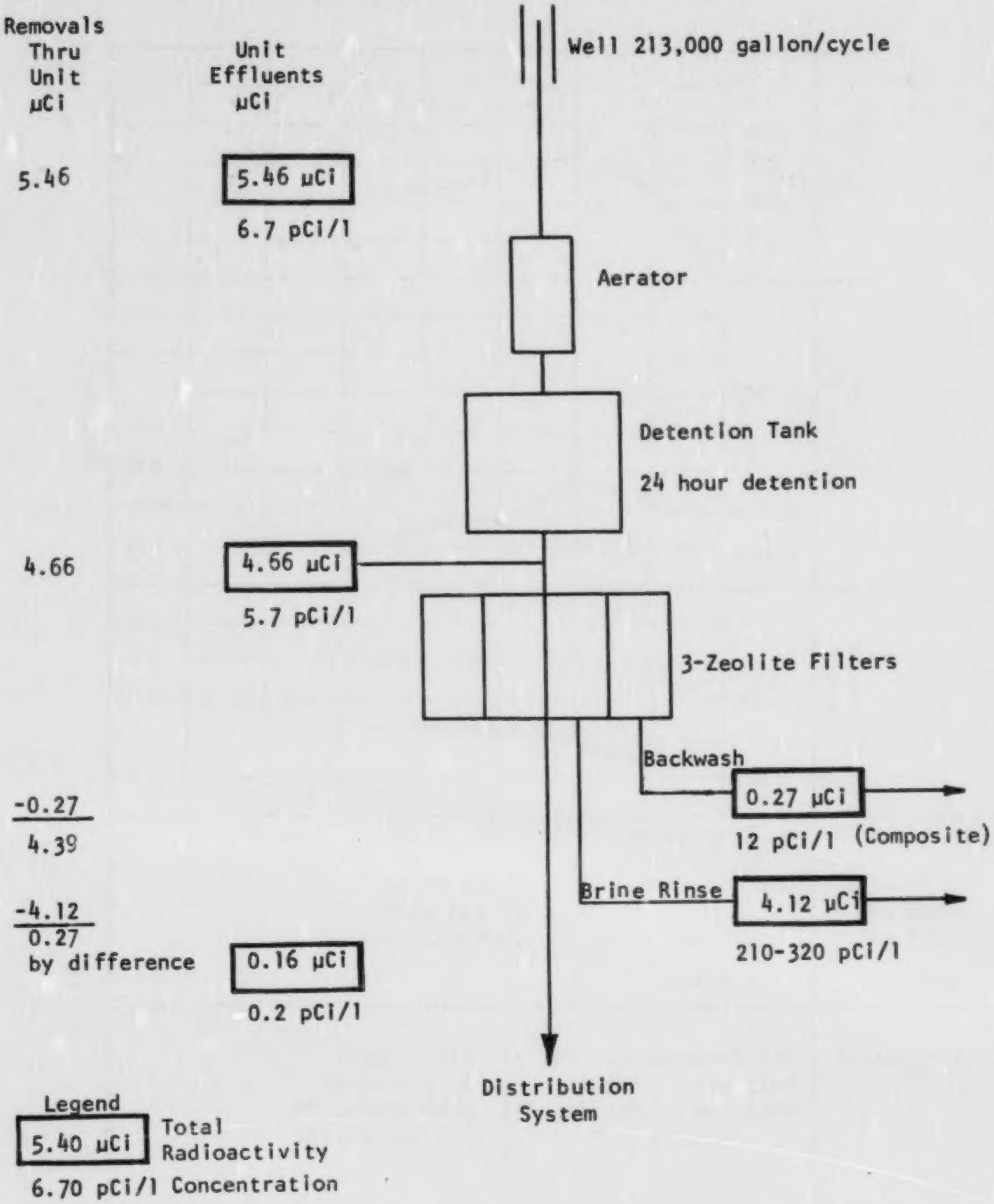
FIGURE 31
Grinnell, Iowa
October 29, 1974

No. 2 Zeolite Softener Brine & Rinse Cycle



Backwash	Brine	Rinse
22 min 318 gpm 7,000 gal Brine 2:18	32 min contact 90 gpm 2,900 gal	60 min rinse 117 gpm flow rate 7,000 gal total flow
Rate 6.34 gpm/sqft	Kgr Hardness 20,000 Salt used 1,454 lb. Salt per cu.ft.7.27 lb	Rinse rate 35 gal/cu.ft. 0.49 gpm/cu.ft. 2.3 gpm/sq.ft.

Figure 32
Ra-226 Distribution in Treatment Process
Grinnell, Iowa
Aeration, Detention and Zeolite Softener Plant


Removals Thru Unit µCi
Unit Effluents µCi
Well 213,000 gallon/cycle
5.46
5.46 µCi
6.7 pCi/l
Aerator
Detention Tank
24 hour detention
4.66
4.66 µCi
5.7 pCi/l
3-Zeolite Filters
Backwash
-0.27
4.39
0.27 µCi
12 pCi/l (Composite)
Brine Rinse
-4.12
0.27
by difference
4.12 µCi
210-320 pCi/l
0.16 µCi
0.2 pCi/l
Distribution System
Legend
5.40 µCi
Total Radioactivity
6.70 pCi/l Concentration

The ion exchanger reduced the radium-226 concentration to 0.2 pCi/l and a total activity of 0.16 µCi for a reduction of 96.5 percent in the softener and an overall reduction of 97 percent. Backwash of the zeolite filter contained 0.27 µCi of radium-226 total radioactivity produced by a concentration of 12 pCi/l and the brine rinse contained 4.12 µCi of radium radioactivity produced by concentrations of 210-320 pCi/l in five samples composited from the rinse. Subtracting the activity removed from the system by the zeolite backwash and brine rinse from the activity remaining in the detention tank leaves a difference of 0.27 µCi compared with the actual 0.16 µCi in the final effluent of the softener. This good correlation indicates a good material balance through the treatment system.

SECTION 12.5

HOLSTEIN

BACKGROUND DATA

Holstein is located in Ida County in Northwest Iowa and located about 12 miles north of Ida Grove,the county seat of Ida County. Like much of Iowa, Ida County's economy is agriculturally oriented and with farm consolidation, the population of Ida County has decreased from 1950 to 1970. However the Town of Holstein with a 1970 population of 1445 has been able to make moderate population increases probably due to light industry in the community.

EXISTING WATER FACILITIES

Holstein presently derives its public water supply from a 644 ft. deep well with a standby source from a 428 ft. deep well described in table 21.

TABLE 21

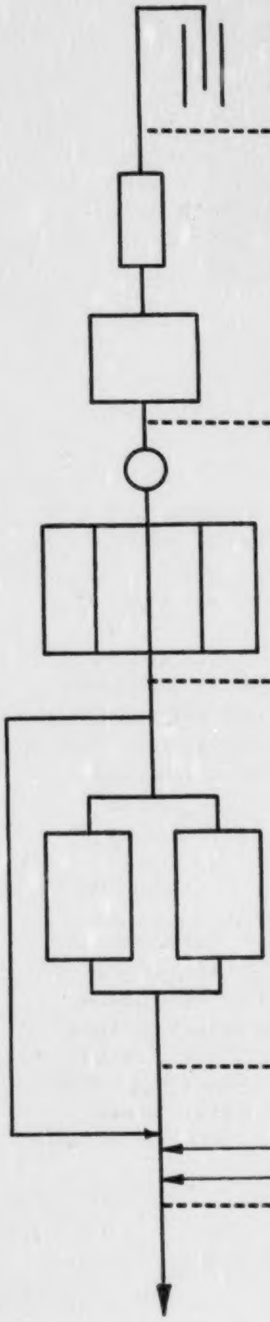
WATER SUPPLY WELLS

Well No.	Year Drilled	Depth	Capacity	Aquifer
1	1937	644'	250 gpm	Dakota
2	1952	428'	90 gpm	Dakota

Figure 33 is a flow diagram of the Holstein iron removal and ion exchange softening plant. Water from the well is pumped at a rate of 250 gpm to a forced draft aerator located above a 27,000 gallon concrete surface storage tank. Transfer pumps of 220 gpm capacity pump the water from the ground storage tank through a 4-cell horizontal pressure iron removal filter containing anthracite media (figure 34). The iron filters are followed by two vertical ion exchange softeners with a rated capacity of 103.5 gpm each. A small percentage of unsoftened water is added to the softener effluent along with the addition of chlorine and soda ash prior to entering a 200,000 gallon surface storage reservoir. The unsoftened water is added to the ion exchange softener effluent to provide for deposition of a protective coating on the water mains. Two 800 gpm high service pumps then transfer the treated water from the ground storage reservoir to the distribution system.

Iron filter backwash and softener backwash and spent brine are discharged to a sanitary sewer which discharges to the municipal lagoon waste water treatment system. The iron filters must be washed

Figure 33
Flow Diagram
Holstein, Iowa - Population 1445 (1970)
Pressure Iron Removal Filter and Zeolite Softener Plant



Well No 1
Depth 644'
Capacity 250 gpm

Forced draft aerator
1250 cfm

Surface detention
Capacity - 27,000 gal
Detention 110 min @ 250 gpm

Filter transfer pump 220 gpm

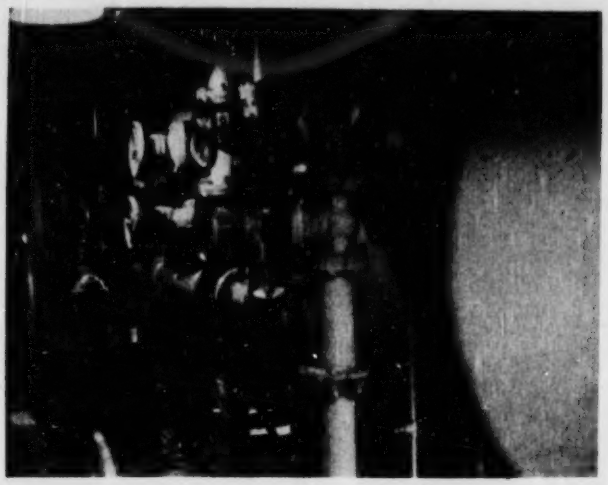
Anthracite pressure filter
4 Cell 8' diam - 16' long
Total area 118 sqft Unit 29.5 sqft
Service rate 220 gpm @ 1.72 gpm/sqft
Backwash rate 295 @ 10 gpm/sqft

Zeolite softeners
2 Cell 8' diam - 9' height
Total area 128 sqft Unit 32 sqft
Media Volume 137 cuft depth 58"
Capacity 55,000 gal
Service rate 110 gpm @ 3.4 gpm/sqft
Backwash rate 140 gpm @ 4.4 gpm/sqft
Backwash Volume 1800 gal

Cl_2
Soda ash

Distribution System

	Parameter and Removal Efficiency		
	Ra-226 pCi/l	Hardness mg/l	Iron mg/l
Well	13	920	1.8
Detention	10 23%	870	1.6 11%
Iron Filter	7.2 28%	885	0.05 97%
Softener	0.5 93%	18 97%	0.02 60%
Overall Removal	96%	98%	99%
System	0.8	346	0.06



Iron Removal Filter
Figure 34

during low sewer flow periods during the very early morning hours to prevent flooding of home basements in the vicinity of the water plant.

IRON FILTER AND ION EXCHANGE PERFORMANCE

Table 22 is a tabulation of the radiological and chemical analyses our stages in the aeration, iron removal, softening and regeneration cycles. Additional mineral analyses are shown in Appendix A. Percentage removals of radium-226, hardness and iron are shown in Figure 33.

Well

The 644 ft. deep well used as the raw water supply for Holstein is the only well in the project study withdrawing water from the Dakota Sandstone formation. The well samples collected at the 30 minute and 4 hour intervals showed a slight increase in radium-226 radioactivity from 12 to 14 pCi/l for the longer pumping period. Other chemical parameters showed no significant changes during the pumping period. The hardness in the well water averaged 910 mg/l, total solids 1355 mg/l and iron 1.8 mg/l. The well water ranked as one of the hardest waters sampled in the project study.

Table 22
Radiological and Chemical Analysis
Holstein, Iowa Water Supply
October 24 & 29, 1974

Sampling Point	Gross Alpha pCi/l	Ra 226 pCi/l	Hard-ness mg/l	Total Solids mg/l	Alkalinity		pH	Iron		Ca mg/l	Mg mg/l	Na mg/l	Mn mg/l	Cl mg/l	SO_4 mg/l
					P mg/l	T mg/l		Total mg/l	Sol mg/l						
Well #1 644' 30 min	35	12	900	1540			7.1	1.8		240	69	110		8	
Well #1 644' 4 hr	26	14	920	1510	0	288	7.1	1.8		240	69	110	0.15	7	800
Aeration-Detention Eff	32	10	870	1510	0	290	7.6	1.6		240	69	110	0.14	7	790
Iron Filter Eff 3 day	34	7	890	1510			7.3	0.01		240	69	120		8	
Iron Filter Eff 7 day	32	7.3	880	1500	0	284	7.35	0.09		240	69	110	0.01	8	790
Softener A Eff 15,000 gal	0.9	0.7	28	1500			7.5	0.09		5.6	3.4	520		14	
Softener A Eff 25,000 gal	1.9	0.4	15	1490	0	276	7.45	0.03		4.0	1.3	510	<0.01	10	790
Softener A Eff 55,000 gal	0.8	0.3	13	1470			7.5	0.02		2.0	1.0	520		8	
Softener B Eff 25,000 gal	4.0	0.5	52	1480			7.65	0.06		12	3.9	530		8	
Softener B Eff 47,000 gal	2.9	1.9	382	1460			7.6	0.02		59	57	350		6	
Blended Plant Eff	4.0	1.0	130	1490			7.6	0.01		33	12	520		30	
Distribution System	3.9	0.8	346	1490			7.7	0.06		90	31	420		16	
Iron Filter BW Comp	240	80	900	1530			7.4	69		240	69	1160		2	
Softener A BW Comp	26	7.8	890	1510			7.4	0.13		240	69	130		9	
Softener A Rinse 5 min	260	210	15400	72600			6.4	0.22		2800	2000	14600		37000	
Softener A Rinse 10 min	1700	700	78000	166000	0	98	6.0	0.78		20000	5000	19000		73000	1200
Softener A Rinse 15 min	2000	1100	65500	211100			5.9	0.97		20000	3800	40000		97500	
Softener A Rinse 20 min	1700	800	33000	169000			6.25	0.76		10000	2000	82000		90000	
Softener A Rinse 25 min	110	70	3900	29100			7.2	0.11		1200	260	12600		17000	

Table 22 lists the concentrations and percentage removals of these pertinent chemical constituents through the process. During the survey period consistent salt dosages could not be applied to the softeners due to operating difficulties with the brine pump and the lack of an operable brine meter which prevented automatic operation of the softening and regeneration cycles. Emergency main repair work by the water plant operator also prevented regeneration at proper intervals.

Iron Removal Filter

Aeration and a theoretical settling time of 110 minutes apparently reduced the radium-226 concentration and iron content from 13 pCi/l and 1.8 mg/l in the well water to 10 pCi/l and 1.6 mg/l respectively in the settled effluent. These values indicate radium and iron removals of 23% and 11% respectively by aeration and settling only.

The radium-226 and iron concentrations of 10 pCi/l and 1.8 mg/l respectively were reduced by passage through the iron removal filter to 7.2 pCi/l and 0.05 mg/l respectively. These values indicate radium and iron removals of 28% and 97% respectively through the iron removal filter.

Ion Exchange

Radiological and chemical analysis shown in table 22 were collected at the 15,000, 25,000, and 55,000 gallon intervals through the softening cycles of softener A. As described previously there were difficulties in applying the proper salt dosage during regeneration and excessive salt was applied to this softner. The softening cycle exceeded 65,000 gallons without exhaustion rather than the design 55,000 gallon capacity. Additional samples were collected from softener B to confirm efficiency of this unit and from the blended plant effluent.

Radium-226

Table 22 shows the radium-226 concentrations were reduced fron an average of 7.2 pCi/l to an average of 0.5 pCi/l following ion exchange softening for a removal of 93% through Softener A. Two radium samples collected from softener B showed values of 0.5 pCi/l at 25,000 gallons and 1.9 pCi/l at 47,000 gallons indicating this softener may not have been regenerated properly due to the brine pump problems. Hardness removal was not as good and both the radium and hardness concentrations were increasing before the normal regeneration time.

Hardness

Total hardness was reduced from 890 mg/l to an average hardness of 18 mg/l through the ion exchange softener for an average hardness reduction of 98%. Hardness values on four samples collected during the softening cycle ranged from 13 to 52 mg/l indicating some hardness leakage with this high hardness water.

It had been planned to run sofener A approximately 10% past its normal point of exhaustion. However, the softener apparently had received an excessive salt dosage at the previous regeneration and was producing a soft water at 65,000 gallons.

Calcium and magnesium ions were reduced by the cation exchanger from average raw water values of 240 and 69 mg/l to average softened values of 4 and 2 mg/l respectively. No significant changes occurred in concentration of total solids, alkalinity and sulfates during the sodium ion exchange softening cycle.

There was a significant increase in sodium from 110 mg/l in the raw water to 520 mg/l in the softened water due to exchange of the sodium ion for the calcium and magnesium ions. This laboratory sodium value of 250 mg/l in softener A is approximately the same as a calculated value of 534 obtained by adding a calculated sodium addition through exchange to the laboratory raw water values.

ION EXCHANGE REGENERATION

Table 22 also indicates the radiological and chemical analyses for the samples collected from the softener discharges at various stages during regeneration. Table 23 gives the best available water usage data during regeneration. Some flows are design rates or estimated rates which could not be checked in the field. Likewise during the sampling period, lack of automatic softener operation because of metering equipment failure and the brine pump problem caused considerable softener overrun at times with unsoftened water reaching the distribution system.

Table 23
Regeneration and Water Use Data

Cycle	Time	Rate	Water Quantity
Softening	10 hrs.	110 gpm	65,000 gal
Backwash	13 min.	140 gpm	1,800 gal
Brine	28 min.	28 gpm	780 gal
Rinse	45 min.	60 gpm	2,700 gal
TOTAL			70,280 gal

These rates and quantities are shown in the plant flow diagram figure 33 and in figure 35 showing the brine and rinse cycle.

Backwash

The ion exchanger backwash sample was composited at two minute intervals over the 13 minute backwash period to determine changes in the radiological and chemical analyses during the backwash. A radium-226 concentration of 7.8 pCi/l indicated little radium was being removed from the filter by the backwash process. Other parameters were quite similar to the iron filter effluent used for the backwash. No visible color or suspended solids were noted in the backwash water indicating excellent removal of iron in the iron removal filter.

Brine and Rinse Cycle

Saturated brine is pumped from a sump and diluted by an ejector flow before passing through the exchange media. Due to brine pump repair needs and lack of a brine meter, accurate rates of flow and amount of brine to the exchanger could not be determined. Salometer degree readings were taken to determine the time at which chlorides of calcium and magnesium and excess regenerant were passing from the softener. Salometer readings were then taken at five minute intervals and samples for radiological and chemical analyses at five minute intervals to indicate changes during the brine-rinse cycle.

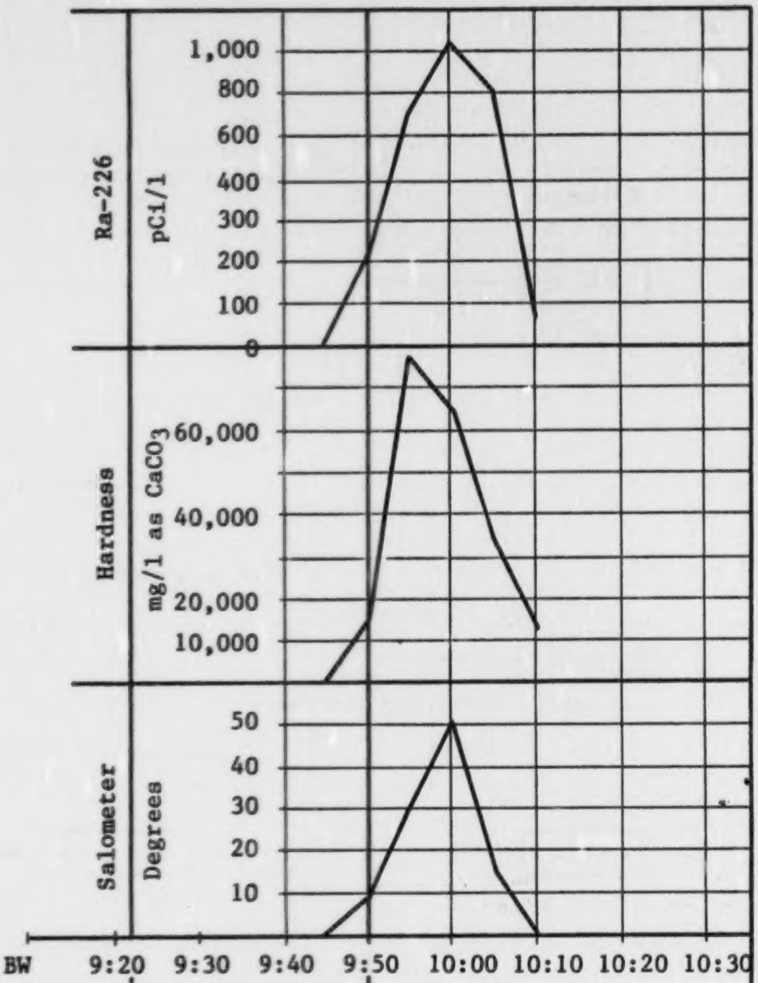
Figure 35 is a graph of the salometer degree readings (includes other ions), hardness and radium-226 determinations of the five samples collected during the brine-rinse cycle. Radium-226 concentrations in the rinse increased to a maximum of 1100 pCi/l, hardness to 78,000 mg/l and the salometer degree readings to 50 percent. The steep salometer degree graph may indicate the brine is being applied too fast with a too short contact time as compared with a recommended "bell" curve. Total solids in the rinse increased to a maximum of 211,100 mg/l, calcium to 20,000 mg/l, magnesium to 5,000 mg/l, sodium to 82,000 mg/l and chlorides to 97,500 mg/l.

RADIUM-226 MATERIAL BALANCE

Figure 36 is a schematic drawing showing the water treatment units and the radium-226 radioactivity at various stages in the treatment unit. The detailed computations are shown in Appendix B. Applying the average 13 pCi/l radium-226 concentration value to the well pumpage of 1.09 million gallons over the 7 day iron filter run gives a total radium-226 radioactivity of 53.7 µCi in the well water pumped during the perod. Using 14 softener regenerations (2/day) gives a total softener service and regeneration cycle water usage of 76,000 gallons and a radium-226

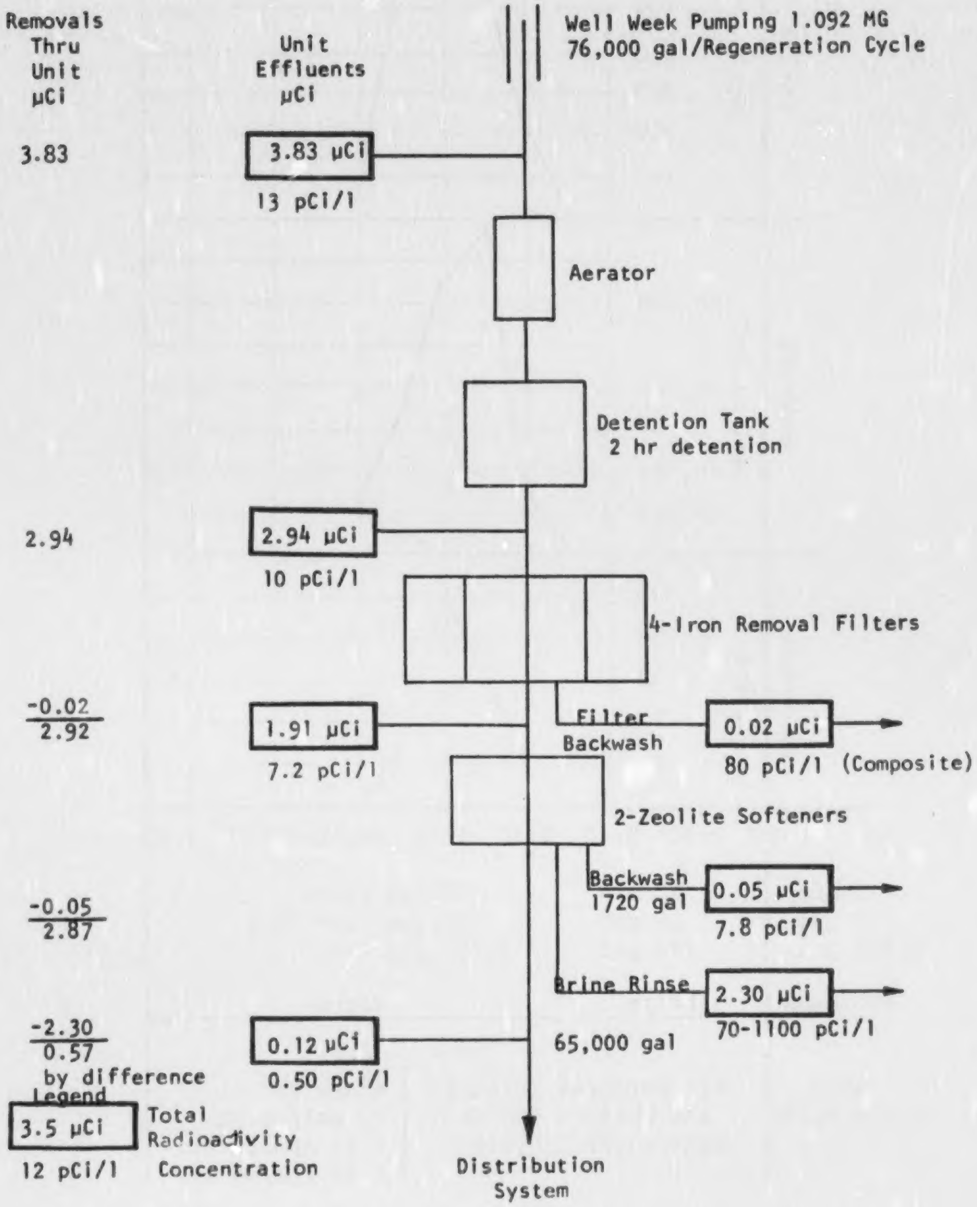
FIGURE 35
Holstein, Iowa
October 29, 1974

No. 1 Zeolite Softener Brine & Rinse Cycle



Backwash	Brine	Rinse
13 min	28 min	45 min rinse
140 gpm	28 gpm	60 gpm flow rate
1,800 gal	780 gal	2,700 gal flow
Rate 10 gpm/sq.ft	Kgr Hardness 20/cu.ft. Salt Used 900 lb. Salt/cu.ft. 6,616	Rinse rate 96 gal/cu.ft. 0.44 gpm/cu.ft. 2.14 gpm/sq.ft.

Figure 36
Ra-226 Distribution in Treatment Process
Holstein, Iowa
Iron Removal and Zeolite Softener Plant


Removals Thru Unit µCi
Unit Effluents µCi
Well Week Pumping 1.092 MG
76,000 gal/Regeneration Cycle
3.83
3.83 µCi
13 pCi/l
Aerator
Detention Tank
2 hr detention
2.94
2.94 µCi
10 pCi/l
4-Iron Removal Filters
-0.02
2.92
1.91 µCi
7.2 pCi/l
Filter Backwash
0.02 µCi
80 pCi/l (Composite)
2-Zeolite Softeners
Backwash
1720 gal
0.05 µCi
7.8 pCi/l
-0.05
2.87
Brine Rinse
2.30 µCi
70-1100 pCi/l
-2.30
0.57
by difference
0.12 µCi
0.50 pCi/l
65,000 gal
Legend
3.5 µCi
12 pCi/l
Total Radioactivity
Concentration
Distribution System

radioactivity of 3.83 μCi for each softener cycle. The 76,000 gallon water usage during this entire softener cycle is greater than the design 55,000 gallon softening cycle and other backwash, brine and rinse waters indicating regenerations were not occurring at proper intervals.

Settling of the iron in the detention tank (2 hour detention) apparently reduced the radium-226 concentration to 10 pCi/l in the aerated and settled water for a radioactivity of 2.94 μCi. The composite radium-226 activity in the filter backwash of only 0.89 μCi was allocated to 0.025 μCi for each of the 14 softener cycles. This value subtracted from the detention tank radioactivity should have approximated the radioactivity in the iron removal filter effluent. Radioactivity removals in the ion exchange backwash and brine rinse were 0.05 μCi and 2.30 μCi respectively.

Subtracting these two waste water radioactivity values from the 2.92 μCi activity leaves a difference of 0.57 μCi which is reasonably close to the 0.12 μCi radium-226 value found in the ion exchange softener effluent.

A 96% reduction in radium-226 was obtained between the raw water (12 pCi/l) and the softened effluent (0.5 pCi/l).

SECTION 12.6

GENERAL ION EXCHANGE

TREATMENT MEDIA

Samples were collected of salt used for sodium cycle regeneration, anthracite media from an iron removal filter and polystyrene resin cation exchange media from the Estherville ion exchange softening plant. Radiological analyses were performed on the treatment media to determine radium-226 accumulations in the media.

The ion exchange resin media samples were collected after backwash by a vertical core sample taken by pushing a 1¼" plastic tube through the 70" media depth just as the bed was being expanded by opening the backwash valve. The bed then was drained completely and the plastic tube core sample withdrawn from the bed. The plastic tube core sample was cut into sections for radiological analysis of the radium content in the bottom, middle and top areas of the softener bed.

Radiological samples on the three types of samples were performed by the State Hygienic Laboratory. Difficulties were encountered in preparing the polystyrene resin media for analysis. Duplicate core samples were also submitted to the Radiochemistry and Nuclear Engineering Facility, Office of Radiation Programs of the U.S. Environmental Protection Agency at Cincinnati, Ohio, for gamma spectral analysis. The results of the radiological analyses of the two laboratories are shown in Tables 24 and 25.

In addition to these analyses, William L. Brinck of the Radiochemistry and Nuclear Engineering Branch and Dr. G. Jacobson, EPA Region VII, conducted measurements of radiation exposure rates on the vertical ion exchange tank surfaces with a portable 5 cm x 5 cm NaI (Tl) survey meter. There was no significant variation in exposure rates on the surface of the tanks during the course of the operating cycle. Thus, over a period of years there is a substantial residual of radioactivity retained within the media which is not removed during regeneration. From the exposure rate measurements and ion exchange core samples, it was determined that the higher concentration of retained radioactivity is located near the interface of the ion exchange media and supporting sand and gravel in the lower portion of the tanks. (See Appendix F.)

SALT UTILIZATION BY ION EXCHANGE

Tables in Appendix E contain computations regarding the salt efficiencies of the four ion exchangers. The salt efficiency, calculated by dividing the salt utilized in removing the hardness by the salt dosage, varied from 55 to 44 percent. These efficiencies indicate about two times the theoretical salt dosage is necessary for media regeneration or conversely about half of the salt dosage passes out of the exchanger or brine waste during the regeneration cycle.

TABLE 24

Salt and Media Sample Radiological Analysis
Estherville, Iowa
State Hygienic Laboratory
Des Moines, Iowa

Sample	Gross Alpha pCi/g	Ra-226 pCi/g
Regeneration Salt (Prior to Use)	0.07	0.06
Leached Sediment on Anthracite	140*	130*
Residue	460*	
Softener Resin (top) Soluble Portion	37*	43*
Residue	280*	
Softener Resin (middle) Soluble Portion	9.3**	9.6*
Residue	140*	
Softener Resin (bottom) Soluble Portion	9.0**	9.7*
Residue	160*	

*pCi/g of original raw granules.
**Gross dissolved soluble reading is slightly smaller than radium-226 results, because of heating process to eliminate corrosive compounds.

TABLE 25

Anthracite & Ion Exchange Core Sample Gamma Spectral Analysis
Estherville, Iowa
National Environmental Research Center
Cincinnati, Ohio

Sample	Ra-226	Ra-228
Anthrafilt (pCi/gm)	225 ± 6	72 ± 2
Ion Exchange Core		
Top (pCi/ml)	36.9 ± 3.1	12.4 ± 0.9
(pCi/gm-wet)	67.9 ± 5.7	22.8 ± 1.6
(pCi/gm-dry)	79.4 ± 6.7	26.7 ± 1.9
Middle (pCi/ml)	37.1 ± 3.2	12.1 ± 0.9
(pCi/gm-wet)	62.2 ± 5.4	20.3 ± 1.4
(pCi/gm-dry)	72.2 ± 6.3	23.6 ± 1.7
Bottom (pCi/ml)	55.7 ± 6.1	16.6 ± 1.7
(pCi/gm-wet)	103.8 ± 11.3	30.9 ± 3.1
(pCi/gm-dry)	116.4 ± 12.7	34.7 ± 3.5

IOWA EXCHANGE MEDIA

Table 26 is a description of the ion exchange media utilized by the municipalities.

TABLE 26

Ion Exchange Media

Municipality	Equipment	Media (1)	Manufacturer
Eldon	General Filter	Dowex HCR	Dow Chemical Co.
Estherville	Permutit	Permutit-Q (2)	Permutit Co.
Grinnell	Refinite	Amberlite & Dowex	Rohm & Hass Dow Chemical Co.
Holstein	General Filter	Dowex HCR	Dow Chemical Co.

(1) All except Estherville are sulfonated polystryene cation exchanger resins with a capacity of approximately 20 Kgr/cu.ft. at a salt dosage of 5 lbs. NaCl/cu.ft.

(2) Specifications state Permutit-Q has a zeolite exchange capacity of 7.4 Kgr/cu.ft. at a salt dosage of 5.5 lbs. NaCl/cu.ft.

SODIUM INCREASE THROUGH ION EXCHANGE

Table 27 is a tabulation of well water hardness and sodium content and the calculated and actual sodium increases in the softened and blended water after the sodium ion exchange process. The basis of concern with sodium in drinking water is the treatment of patients with congestive heart failure, hypertension and certain other kidney and liver diseases.

Both the Estherville and Holstein water supplies had considerable increases in sodium content due to high hardness even though initial contents were low. The Holstein supply had the highest calculated and actual sodium content. During the course of the survey, approximately 20 persons came to the Holstein plant daily to secure unsoftened water in jugs or other containers. These individuals had been advised by their medical doctors to use the unsoftened water for drinking and cooking purposes. This was not a common practice at the other ion exchange softening plants.

Table 27
Sodium Increases Thru Ion Exchange Plants

Town	Well Hardness Raw mg/l	Initial Sodium Raw mg/l	Sodium Increase due to Hardness mg/l (1)	Initial plus Hardness Sodium mg/l (2)	Actual Sodium After Ion Exchange mg/l (3)	System Sodium After Blend mg/l	Comparable Changes in Ra-226 pCi/l		
							Raw.	Fin.	Sys.
Eldon	375	270	173	443	430	420	49	1.9	8.6
Estherville	915	64	422	486	420	420	5.7	0.3	0.4
Grinnell	387	120	178	298	290	260	6.7	0.2	1.4
Holstein	920	110	424	534	520	420	12	0.5	0.8

(1) Sodium increase = Total hardness ÷ 2.17

(2) Initial Sodium plus calculated sodium due to hardness

(3) Laboratory analysis of zeolite softener effluent

SECTION 13

LIME-SODA ASH SOFTENING

SECTION 13.1

PROCESS DESCRIPTION

The hardness of almost all water supplies is caused by the presence in solution of calcium and magnesium compounds. Other bivalent ions such as strontium, ferrous iron and manganese may contribute to the hardness to a much lesser degree. The softening process consists of removing a part of these salts from the water to reduce the hardness to a predetermined value consistent with reduction of detergent consumption, the control of scale formation, and other factors which make for a high quality water. Radium-226 is a divalent ion which would be expected to be removed with the other divalent ions in the softening process.

Calcium and magnesium bicarbonates are alkaline minerals designated as "carbonate hardness" and calcium and magnesium sulfates or chlorides and nitrates are neutral salts designated as "non-carbonate hardness. The alkalinity determination on raw water ordinarily measures the carbonate hardness but in some softened waters alkalinity may also include some sodium alkalinity if the total alkalinity exceeds the total hardness. Sodium alkalinity is often termed "negative non-carbonate hardness" since on reacting with lime, sodium carbonate is formed where it is used for removing noncarbonate hardness. The noncarbonate hardness is measured by the difference between the total hardness and the carbonate hardness and requires soda ash for its reduction or removal. The sum of the alkalinity plus the noncarbonate hardness equals the total hardness if the water contains no sodium alkalinity.

This process of softening depends on the use of lime and soda ash to change the soluble calcium and magnesium compounds into nearly insoluble compounds which are flocculated, settled, and filtered. The chemical reactions are shown below with the precipitated compounds underlined.

$$CO_2 + Ca(OH)_2 = \underline{CaCO_3} + H_2O \qquad (1)$$
$$Ca(HCO_3)_2 + Ca(OH)_2 = \underline{2CaCO_3} + 2H_2O \qquad (2)$$
$$Mg(HCO_3)_2 + Ca(OH)_2 = \underline{CaCO_3} + MgCO_3 + 2H_2O \qquad (3)$$
$$MgCO_3 + Ca(OH)_2 = \underline{Mg(OH)_2} + \underline{CaCO_3} \qquad (4)$$
$$MgSO_2 + Ca(OH)_2 = \underline{Mg(OH)_2} + CaSO_4 \qquad (5)$$
$$CaSO_4 + Na_2CO_3 = \underline{CaCO_3} + Na_2SO_4 \qquad (6)$$

The carbon dioxide is not hardness-forming but it must be removed by lime; also the magnesium carbonate produced in reaction (3) is not sufficiently insoluble for effective removal and so must be changed by additional lime, as in reaction (4) to magnesium hydroxides: The calcium sulfate produced in reaction (5) is soluble and must be changed to calcium carbonate by reaction (6) indicating the need for using soda ash; while soluble calcium and magnesium chlorides are also removed by soda ash with reactions similar to (6).

EXCESS LIME TREATMENT FOLLOWED BY RECARBONATION

The cities of Webster City and West Des Moines in the project study employ the excess-lime treatment followed by recarbonation. With hard-waters containing 40 mg/l or over magnesium (as $CaCO_3$), treatment with excess lime to remove magnesium is usually necessary. The process in both cities consists of primary suspended solids contact only and sedimentation with lime treatment to precipitate the magnesium. After the precipitated magnesium hydroxide and calcium carbonate have settled, but before filtration, the settled water is recarbonated to produce a pH of about 8.7 so as to convert the residual calcium carbonate into the soluble bicarbonate and prevent after-precipitation on the filter sand.

Normally, soda ash is added as needed to precipitate the non-carbonate hardness, but due to the soda ash shortage, the West Des Moines plant was using only a small quantity. The Webster City plant was using lime only during the August, 1974, survey but was using soda ash during the February, 1975, resurvey.

A low magnesium content is desirable since precipitation of magnesium hydroxide may occur within hot water heaters and be carried into hot water lines and deposited there. In the single flocculation basin plant complications arise since conditions for carrying out the precipitation of calcium and magnesium vary in that different pH levels are needed for each, about pH 9.5 for maximum precipitation of calcium carbonate and pH 10.5 for maximum precipitation of magnesium hydroxide.

More economical treatment can be provided by primary flocculation and sedimentation with lime treatment to produce a pH of 10.6 to precipitate the magnesium. The water is then recarbonated with carbon dioxide to lower the pH to 9.4 and precipitate calcium carbonate in the secondary basin with soda ash added as necessary to precipitate non-carbonate hardness. In this procedure any soda ash required is added after recarbonation for because magnesium hydroxide precipitated in the primary treatment absorbes an appreciable amount of negative ions thus reducing the non-carbonate hardness. To obtain full effect of this adsorption, soda ash is added after the magnesium hydroxide is settled.

Lime-soda ash softening is aided by the use of alum, ferric sulfate, sodium aluminate or polyelectrolytes to coagulate the fine crystals formed by the softening reactions. The use of alum may form not aluminum hydroxide but magnesium aluminate so that the magnesium will be more effectively precipitated. High magnesium waters produce a sludge containing a high proportion of magnesium hydrates which are lighter than calcium carbonates.

The suspended solids contact units employed by both the Webster City and West Des Moines plants perform solids contact mixing, coagulation and solids-water separation in a single package type basin. The suspended solids contact action makes the units particularly adapted to calcium carbonate precipitation. The West Des Moines plant has a secondary solids contact tank which was being used only for additional settling due to an incrusted line between the two basins.

SECTION 13.2

WEBSTER CITY

BACKGROUND DATA

Webster City is the county seat of Hamilton County in north central Iowa and, with a 1970 population of 8,488, is the largest city in the County. Hamilton County is primarily agriculturally oriented and the county has shown a slight population increase during the past decade.

EXISTING WATER FACILITIES

Webster City presently derives its public water supply from two Jordan aquifer wells constructed to a depth of 2005 feet. Both are pumped by vertical turbine pumps with capacities of 850 to 950 gpm. The original lime softening plant was constructed in 1949 and was enlarged to include a second suspended solids contact softener in 1963. Treatment presently consists of forced draft aeration, upflow clarification, recarbonation and filtration.

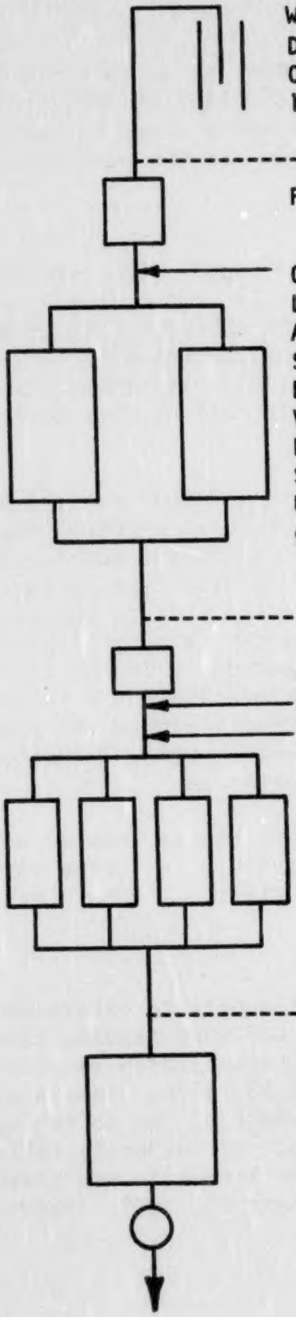
Figure 37 is a flow diagram of the Webster City lime-soda ash softening plant. Raw water from the two wells is pumped through a forced draft aerator and flows directly to two parallel solids contact softeners. One of the softeners is the older rectangular Permutit type contact unit and the newer softener is a rectangular General Filter contact unit. The design rate is 1,000 gpm for each unit with a total plant capacity of approximately 2.9 million gallons per day. The clarifier effluent then passes by gravity through a recarbonation basin to four sand filters. Recarbonation is provided by a compressed CO_2 storage tank. Finished water storage is provided by a clear well, 1,400,000 gallon surface storage reservoirs and elevated storage.

Lime sludge is discharged to two earthen settling basins located adjacent to the Boone River. The settling basins operate in series with the supernatant from the second discharging to the river.

SOLIDS CONTACT SOFTENER AND FILTER PERFORMANCE

Two surveys were conducted at this public water supply to determine treatment efficiencies when feeding lime alone and when feeding lime plus soda ash to secure non-carbonate hardness removal with resultant better radium and hardness removal. The August 13, 1974, plant survey was conducted without soda ash being used as a part of the softening process as a result of the shortage of soda ash. During early February a supply of soda ash was obtained and the normal lime-soda ash treatment process was being used at the time of the February 20, 1975, survey.

Figure 37
Flow Diagram
Webster City
Lime-Sode Ash Softening Plant
Population 8,488 (1970)
August 13, 1974



Well	No 1	No 5
Depth ft	2005	2005
Capacity	850	850

1700 gpm total pumpage

	Parameter and Removal Efficiency	
	Ra-226 pCi/l	Hardness mg/l
Well	6.1	507

Forced Draft Aerator

Chemical Dosages lb/mg 8-13-74
Lime 1560 Soda Ash 0
Alum 0 Floc Aid 32 oz

Solids Contact	No 1	No 2
Design - 1000 gpm		
Volume - gal	72,000	91,000
Detention - Min	72	91
Surface area-sqft	750	930
Upflow rate - gpm/sqft	1.25	1.25

	Ra-226 No 1	Ra-226 No 2	Hardness No 1	Hardness No 2
Clarifier Effluent	1.9 68%	2.6 57%	333 32%	282 43%

CO_2
Phosphate
Cl_2

Filter
4 @ 16 x 14 - 224 sqft
Total 896 sqft
Filter rate 2.2 gpm/sqft
Backwash rate 15 gpm/sqft

	Ra-226	Hardness
Filter Effluent	0.9 60%	262 15%
Overall Removal	85%	48%

Clearwell
and Ground Storage

700, 1000, 1000, 1300 gpm pumps

Distribution System

Table 28 is a tabulation of the radiological and chemical analyses performed on samples collected August 13, 1974 from the two wells and from various stages in the process. Additional mineral analyses are shown in Appendix A. Percentage removals of radium-226 and hardness for the August 13, 1974, survey are also shown on the plant flow diagram, figure 37.

Table 29 is a similar tabulation of the radiological and chemical analyses performed on samples collected during the February, 1975, survey.

Wells

Both of the 2,005 foot deep wells obtain water from the Jordan Sandstone formation and both are pumped at an 850 gpm rate. There were considerable variations in the radium and hardness characteristics during early pumping periods and after extended pumping times. Wells 1 and 5 had radium-226 concentrations of 2.2 and 7 pCi/l respectively after 30 minute pumping and 5.1 and 7.1 pCi/l respectively, after a 6 hour pumping period. After the longer pumping period the Wells 1 and 5 showed a hardness of 485 and 530 mg/l respectively, and a total solids content of 685 and 1,010 respectively.

No well samples were collected during the follow-up survey on February 20, 1975, but it is assumed that the aerator effluent radium-226 and hardness values of 7.8 pCi/l and 482 mg/l represented both wells.

Solids Contact Softening and Filtration

Table 30 lists the concentrations and percentage removals of the radium and other chemical constituents through the system. Data for both the August 13, 1974, and February 20, 1975, surveys are included in the table. Generally, average values or representative sample values were used in determining the percentage removals.

Radium-226

There were considerable variations in the radium removal data for clarifier effluent during the August survey when lime alone was used for softening. The radium-226 concentration was reduced from an average of 6.1 pCi/l in the well water to 1.9 and 2.6 pCi/l in clarifiers 1 and 2 effluents respectively. These are overall removals of 68 percent and 57 percent respectively. Surprisingly, clarifier No. 1 which had the best radium removal had the poorest hardness (32 percent) removal. There appeared to be no apparent difference in chemical dosage or operation during the project study.

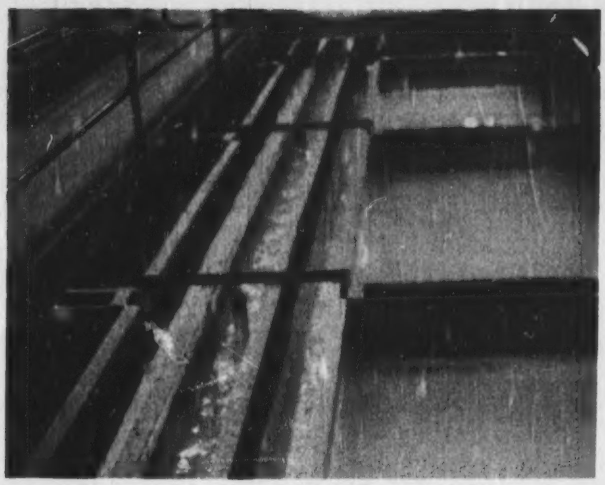
Table 28
Radiological and Chemical Analysis
Webster City, Iowa Water Supply
August 13, 1974

Sampling Point	Gross Alpha pCi/l	Ra 226 pCi/l	Hard- ness mg/l	Total Solids mg/l	Alkalinity P mg/l	Alkalinity T mg/l	pH	Iron Total mg/l	Iron Sol mg/l	Ca mg/l	Mg mg/l	Na mg/l	Mn mg/l	Cl mg/l	SO_4 mg/l
Well #1 2005' 25 min	5.9	2.2	560	841	0	344	7.1			130	71				320
Well #1 2005' 6 hr	5.2	5.1	485	685	0	304	7.5			120	56				390
Well #5 2005' 30 min	14	7	450	981	0	294	7.0			120	48				400
Well #5 2005' 6 hr	14	7.1	530	1010	0	294	7.3	0.69	0.69	110	48	130	0.01	71	380
Aerator Eff 30 min	21	5.9	475	941	0	302	7.5			120	53				390
Aerator Eff 5 hr	20	6.8	510	971	0	296	7.75	0.64	0.64	110	50	120	0.01	65	390
Clarifier #1 Eff 6 hr	4.4	1.9	332	809	18	33	10.0			69	43				390
Clarifier #1 Eff Dup	1.3	1.3	334	801	13	39	10.1			69	43				380
Clarifier #2 Eff 6 hr	2.4	2.6	282	751	18	76	10.1			49	43				400
*Clarifier #1 Sludge Comp	1382	1269		95650						35130	1610	114			1710
*Clarifier #2 Sludge Comp	894	959		72282						26500	1140	94			1650
*Filter #4 Backwash 2 min	178	315		7263						2400	110	8			150
Filter #2 Eff 5 hr	1.8	0.9	260	739	42	84	9.3			39	44				390
Filter #4 Eff 5 hr	3.6	0.9	264	746	32	84	9.3	0.02	0.02	39	44	110	0.01	62	370

*Clarifier #1 Sludge	Suspended Solids	94,950 mg/l
*Clarifier #2 Sludge	Suspended Solids	71,606 mg/l
*Filter #4 Backwash	Suspended Solids	6,500 mg/l

Table 29
Radiological and Chemical Analysis
Webster City, Iowa Water Supply
February 20, 1975

Sampling Point	Gross Alpha pCi/l	Ra 226 pCi/l	Hard-ness mg/l	Total Solids mg/l	Alkalinity		pH	Iron		Ca mg/l	Mg mg/l	Na mg/l	Mn mg/l	Cl mg/l	SO_4 mg/l
					P mg/l	T mg/l		Total mg/l	Sol mg/l						
Aerator Eff (2 wells)	10	7.8	482	977	0	296	7.8	0.56		110	49				
Clarifier #1 Eff 8 hr	5.3	0.9	150	758	54	80	10.95	0.03		34	17				
Clarifier #2 Eff 8 hr	1.6	0.3	150	767	54	82	10.95	0.04		34	17				
Clarifier #1 Sludge Comp	1200	880		106000			10.95			34000	3400				105000
Clarifier #2 Sludge Comp	2200	1000		88900			10.85			41000	4000				88300
Filter #1 Eff	1.3	0.3	186	793	36	104	9.9	0.12		43	22				
Filter #4 Eff 30 hr	0.6	0.3	106	725	34	94	9.85	0.05		13	19				
Filter #3 BW Comp	50	50	3870	4700	32	86	9.7	4.9		1400	100				



Rectangular Solids Contact Unit
Figure 38

There was a considerable improvement in both radium removal and hardness removal during the February, 1975, survey when both lime and soda ash were used for softening. The wells have an average non-carbonate hardness of over 180 mg/l and residual hardness is high. Lime does remove magnesium non-carbonate hardness but, for each molecule of magnesium non-carbonate hardness removed, an equivalent molecule of calcium non-carbonate hardness is formed.

During the February, 1975, survey the radium-226 concentration was reduced from an average of 7.8 pCi/l in the aerator effluent (from both wells) to 0.9 and 0.3 pCi/l in clarifiers No. 1 and 2 respectively, even though hardness removals through the clarifiers were identical. Clarifier No. 1 had the best radium removal but as noted had the poorest removal on the previous survey. The two clarifiers had radium removals of 88 and 96 percent respectively, which is a considerable increase over the 68 and 57 percent radium removals on the previous survey when lime alone was used.

Filtration through sand filters showing considerable calcium carbonate encrustation effected some removal of radioactivity. Filter No. 4 is newly rebuilt and was producing a turbidity of 2 turbidity units compared with approximately 50 turbidity units in the Filter No. 1 effluent with a very coarse encrusted media. Radium-226 concentration was reduced from an average 2.2 pCi/l in the clarifier effluent during the August, 1974, survey to 0.9 pCi/l in both filter effluents going to the clearwell and distribution system. Likewise, during the February, 1975, survey, the radium-226 concentration was reduced from an average of 0.6 pCi/l in the two clarifier effluents to 0.3 pCi/l in both filter effluents. The two filters achieved average radium-226 removals of 60 percent on the August, 1974, survey and 50 percent on the latter survey.

TABLE 30

Radium-226, Hardness, Calcium, and Magnesium Removals
Solids Contact Softeners and Filtration
Webster City, Iowa

Sampling Point	Radium-226		Hardness		Calcium		Magnesium		pH
	pCi/l	Percent Removal	Mg/l	Percent Removal	Mg/l	Percent Removal	Mg/l	Percent Removal	
August 13, 1974 (Lime - No Soda Ash)									
Well	6.1		507		120		50		7.4
Clarifier #1 Eff.	1.9	68	333	32	69	42	43	14	10.0
Clarifier #2 Eff.	2.6	57	282	43	49	29	43	0	10.1
Filter #2 Eff.	0.9	60	260	15	39	20	44	0	9.3
Filter #4 Eff.*	0.9	60	264	15	39	20	44	0	9.3
Overall	0.9	85	262	48	39	68	44	14	
February 20, 1975 (Lime-Soda Ash)									
Aerator Eff.	7.8		482		110		49		7.8
Clarifier #1 Eff.	0.9	88	150	69	34	69	17	65	10.95
Clarifier #2 Eff.	0.3	96	150	69	34	69	17	65	10.95
Filter #1 Eff.	0.3	50	186	--	43	--	22	--	9.9
Filter #4 Eff.*	0.3	50	106	29	13	69	19	--	9.85
Overall	0.3	96	106	78	13	85	19	61	

*Low turbidity from this filter.

The overall radium-226 reduction was 85 percent with lime softening (pH-10.1) and 96 percent with lime-soda ash softening (pH-10.95) with effluent concentrations of 0.9 and 0.3 pCi/l respectively.

Hardness

Table 30 indicates much higher hardness removals were accomplished with the lime-soda ash chemical treatment during the February, 1975, survey. During the August, 1974, survey, hardness was reduced from an average hardness of 507 mg/l in the well water to values of 333 and 282 mg/l in the clarifier No. 1 and 2 effluents. These are unit removals of 32 percent and 43 percent respectively. This compares with the February survey which showed hardness reductions from 482 mg/l in the aerator effluent (two wells) to 150 mg/l in both clarifier effluents for a 69 percent removal.

During the August, 1974, survey, hardness was reduced from an average 307 mg/l to 260 and 264 mg/l in the two filters for a process hardness removal of 15 percent. During the February, 1975, survey the No. 1 filter which was encrusted showed an actual hardness and some other chemical constituent increases. The No. 4 filter which produced a relatively turbidity-free effluent showed a reduction in hardness and other chemical constituents for a hardness removal of 29 percent. The overall hardness reduction through all units was 78 percent with a final hardness of 106 mg/l.

Calcium decreased from 120 mg/l to 39 mg/l following the lime treatment process and from 110 mg/l to 13 mg/l with the lime-soda ash treatment process. Magnesium showed a small increase with the lime treatment process and decreased from 49 mg/l to 19 mg/l with lime-soda ash treatment for an overall reduction of magnesium of 61 percent.

RADIUM-226 MATERIAL BALANCE

Figure 39 is a schematic drawing showing water treatment units and the radium-226 activity at various stages in the treatment process. The data is from the August 13, 1974, survey when lime alone was used for treatment. Detailed computations are shown in Appendix B.

Applying the average 6.1 pCi/l concentration value to the well pumpage of 1.32 million gallons for the daily pumpage gives a total radium activity of 30.6 µCi in the well pumpage. Settling of the coagulated and softened water in the solids contact softener (upflow clarifier) reduced the radium-226 concentration in the clarifier effluent to 2.2 pCi/l. It was impossible at the time of the survey to accurately measure the timed continuous sludge blowoff. Consequently, the radioactivity in the sludge drawoff was calculated from the estimated solids removal in the softening process. The average 1,114 pCi/l radium concentration applied to the calculated gallons of lime sludge gave a radium-226 radioactivity of 24.6 µCi in the sludge drawoff.

Backwash of the sand filters contained a radium concentration of 92 pCi/l, which applied to the average quantity of backwash water for the day, produced a radium-226 radioactivity of 5.6 µCi prorated for the daily pumpage. Subtracting the radioactivity removed by the lime sludge drawoff and filter backwash from the total well radioactivity leaves a difference of 0.4 µCi radioactivity compared with the value of

4.4 μCi in the sand filter effluent. Flow lost by filter backwash was not considered in the sand filter effluent flow computation. This is not a good material balance through the treatment system.

Similar computatons and schematic drawing (Figure 40) were also developed for a plant study in February, 1975, when lime and soda ash were used as softening chemicals. A higher radium removal is evident from the higher (32.6 μCi) radioactivity in the sludge drawoff on the later survey. Likewise, the better removal is evident in the much lower total radioactivity (2.7 and 1.36 μCi) in the clarifier effluent and filter effluent with the lime-soda-ash softening.

Figure 39
Ra-226 Distribution in Treatment Process
Webster City, Iowa
Lime-Soda Ash Softening Plant
August 13, 1974

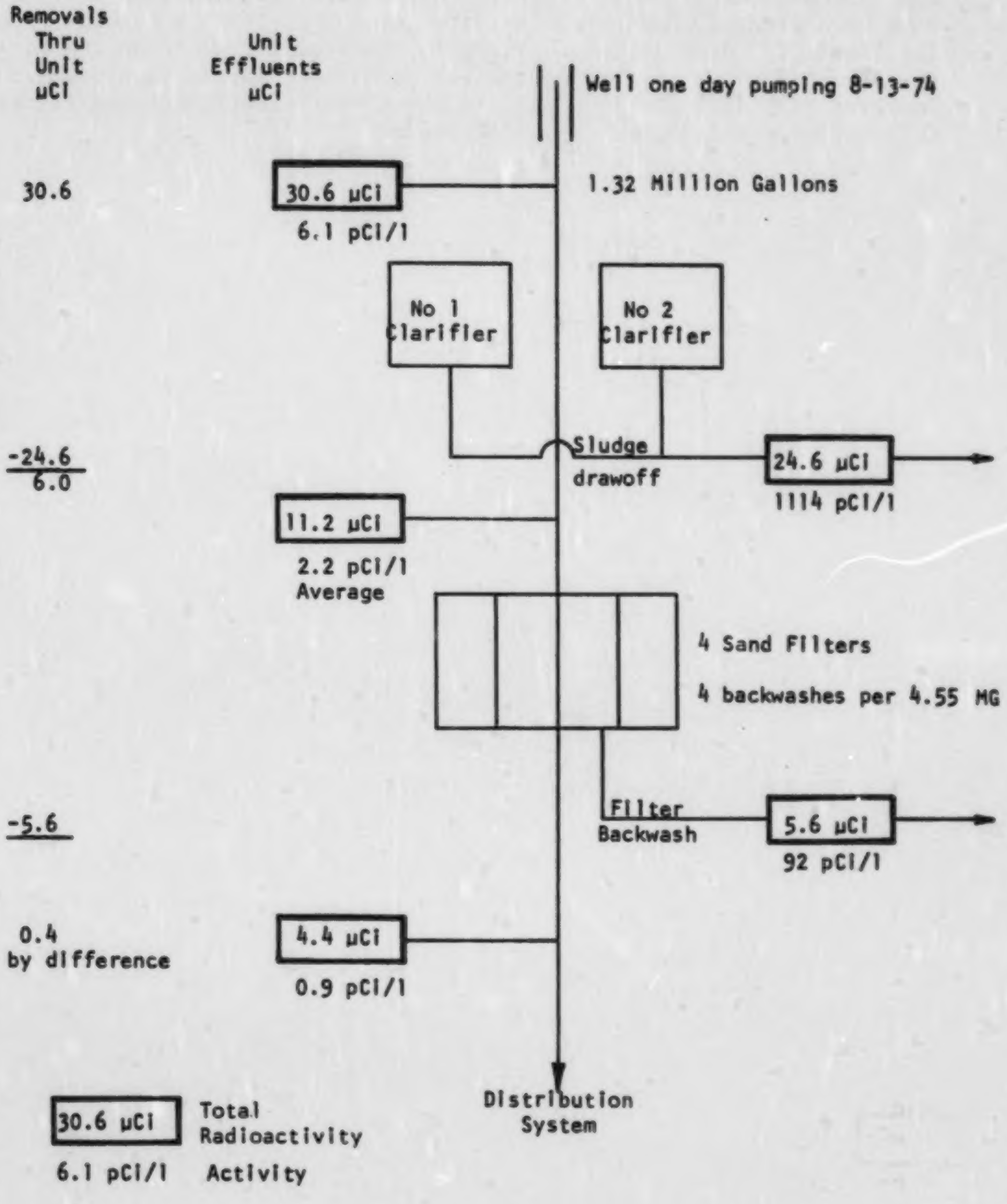
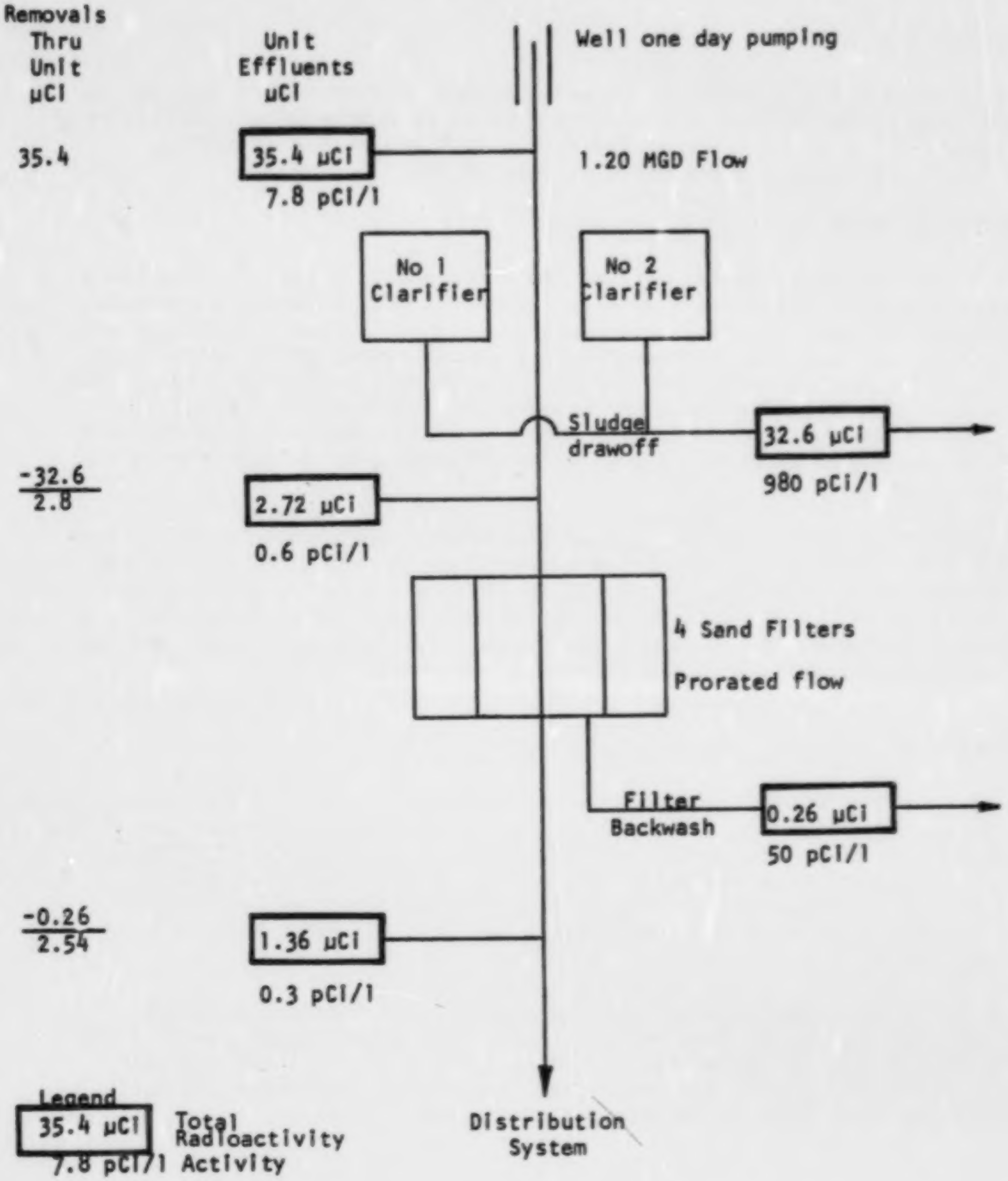

Removals Thru Unit µCi
Unit Effluents µCi
Well one day pumping 8-13-74
1.32 Million Gallons
30.6
30.6 µCi
6.1 pCi/l
No 1 Clarifier
No 2 Clarifier
-24.6
6.0
Sludge drawoff
24.6 µCi
1114 pCi/l
11.2 µCi
2.2 pCi/l Average
4 Sand Filters
4 backwashes per 4.55 MG
-5.6
Filter Backwash
5.6 µCi
92 pCi/l
0.4 by difference
4.4 µCi
0.9 pCi/l
Distribution System
30.6 µCi
6.1 pCi/l
Total Radioactivity
Activity

Figure 40
Ra-226 Distribution In Treatment Process
Webster City, Iowa
Lime-Soda Ash Softening Plant
February 20, 1975


Removals
Thru
Unit
µCi
Unit
Effluents
µCi
Well one day pumping
35.4
35.4 µCi
7.8 pCi/l
1.20 MGD Flow
No 1
Clarifier
No 2
Clarifier
Sludge
drawoff
32.6 µCi
980 pCi/l
-32.6
2.8
2.72 µCi
0.6 pCi/l
4 Sand Filters
Prorated flow
Filter
Backwash
0.26 µCi
50 pCi/l
-0.26
2.54
1.36 µCi
0.3 pCi/l
Distribution
System
Legend
35.4 µCi
Total
Radioactivity
7.8 pCi/l
Activity

SECTION 13.3

WEST DES MOINES

BACKGROUND DATA

West Des Moines, located at the western edge of Polk County adjacent to the City of Des Moines is a rapidly growing community with a 1970 population of 16,441 as compared with a 1950 population of 5,615. Present population is estimated at over 20,000.

EXISTING WATER FACILITIES

West Des Moines presently derives its water supply primarily from two Jordan aquifer wells and from eight shallow gravel pack wells averaging 42 feet in depth. During past years an average of over one million gallons per day has been purchased from a nearby cement plant which has a Ranney collection well about a mile from the water treatment plant. The primary source during the study was the two Jordan wells 2,460 ft and 2,480 ft in depth and pumping at about 1,100 gpm each. The water table from the Jordan sandstone formation has dropped over 60 feet during the past year.

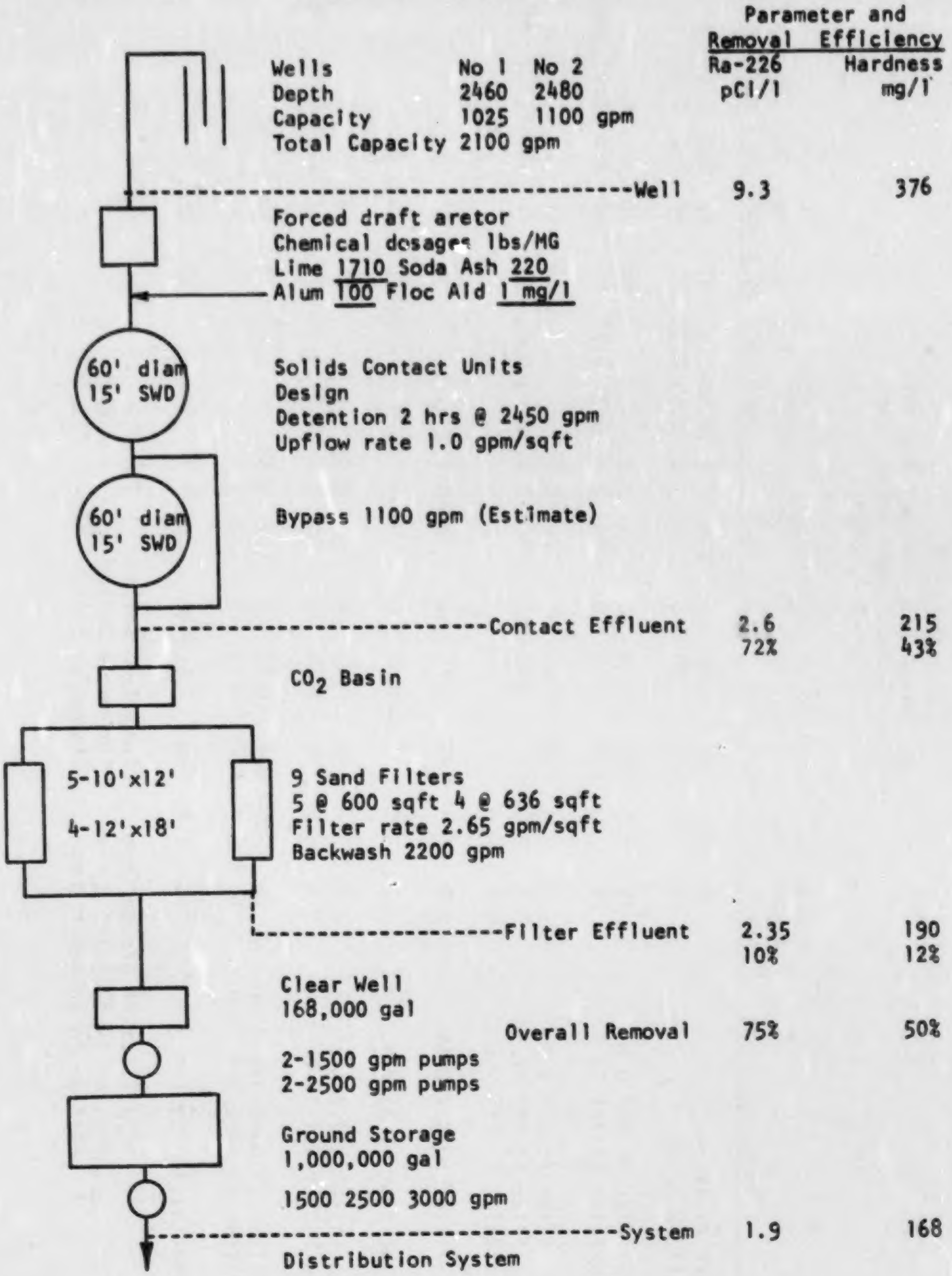
Figure 41 is a flow diagram of the West Des Moines lime-soda ash softening plant. The plant originally was an iron removal plant serving the shallow wells, softening was added in 1962 and the plant capacity enlarged in 1972. Raw water from the two deep wells used during the survey is pumped to a forced draft aerator and flows by gravity through the suspended solids contact softeners, recarbonation basins and sand filters.

SOLIDS CONTACT SOFTENER AND FILTER PERFORMANCE

The West Des Moines lime-soda ash solids contact units (figure 42), designed for series operation, could not be used in this manner at the time of the survey due to an encrusted line between the contact units. The second solids contact tank was being used primarily for additional settling time for a portion of the treated flow. In addition, due to limited availability of soda ash, very little was used for non-carbonate hardness removal.

Table 31 is a tabulation of the radiological and chemical analyses performed on the two deep wells utilized during the survey and from the various stages in the process. Additional mineral analyses are shown in Appendix A. Percentage removals of radium-226 and hardness are also shown on the plant flow diagram, Figure 41.

Figure 41
Flow Diagram
West Des Moines, Iowa
Lime-Soda Ash - Softening Plant
Population 16,440 (1970)



Wells	No 1	No 2
Depth	2460	2480
Capacity	1025	1100 gpm
Total Capacity	2100 gpm	

Forced draft aretor
Chemical dosages lbs/MG
Lime 1710 Soda Ash 220
Alum 100 Floc Aid 1 mg/1

Solids Contact Units
Design
Detention 2 hrs @ 2450 gpm
Upflow rate 1.0 gpm/sqft

Bypass 1100 gpm (Estimate)

CO_2 Basin

9 Sand Filters
5 @ 600 sqft 4 @ 636 sqft
Filter rate 2.65 gpm/sqft
Backwash 2200 gpm

Clear Well
168,000 gal

2-1500 gpm pumps
2-2500 gpm pumps

Ground Storage
1,000,000 gal

1500 2500 3000 gpm

Distribution System

	Parameter and Removal Efficiency	
	Ra-226 pCi/1	Hardness mg/1
Well	9.3	376
Contact Effluent	2.6 72%	215 43%
Filter Effluent	2.35 10%	190 12%
Overall Removal	75%	50%
System	1.9	168

Table 31
Radiological and Chemical Analysis
West Des Moines, Iowa Water Supply
August 1, 1974

Sampling Point	Gross Alpha pCi/l	Ra 226 pCi/l	Hard-ness mg/l	Total Solids mg/l	Alkalinity P mg/l	Alkalinity T mg/l	pH	Iron Total mg/l	Iron Sol mg/l	Ca mg/l	Mg mg/l	Na mg/l	Mn mg/l	Cl mg/l	SO_4 mg/l
Well #1 12 hr	26	9.6	376	1200	0	260	7.5	0.36	0.36	87	40	250	<0.01	65	550
Well #2 12 hr	24	11	372	1200	0	258	7.5	0.33	0.33	88	40	250	0.01	67	570
Clarifier #1 Inf 8 hr	29	8.6	376	1210	0	264	8.0			88	40				580
Clarifier #1 Inf 12 hr	29	10	376	1180	0	260	8.0	0.25	0.25	88	40	250	0.01	65	570
Clarifier #1 Eff 8 hr	5.0	2.9	242	1063	52	84	10.1			49	31				570
Clarifier #1 Eff 12 hr	7.3	2.6	188	1030	56	80	10.4	0.03	0.03	33	27	260	0.01	66	580
Clarifier #1 Eff Dup	6.5	2.4													
Clarifier #2 Eff 8 hr	3.4	2.8	192	1019	50	78	10.2			36	27				570
*Clarifier #1 Sludge	3312	2300		145500						50470	3750				4760
New Filter Eff 8 hr	7.1	2.4	188	1030	46	96	9.35			31	28				560
New Filter Eff 12 hr	8.1	2.3	192	1010	30	90	9.5	0.01	0.01	31	27	240	0.01	68	590
*Filter #4 Backwash 2 min	33	12	455	1278	48	144	9.55			130	40				570
*Filter #4 Backwash Comp	19	6.3	410	1273	48	132	9.6			110	38				570
Distribution System	5.4	1.9	168	951	48	80	9.7			28	26				520

*Clarifier #1 Sludge Comp	Suspended Solids	144,200
*Filter #4 Backwash 2 min	Suspended Solids	126
*Filter #4 Backwash Comp	Suspended Solids	222

Solids Contact Softeners
Figure 42

Wells

Both of the deep wells, 2,460 ft in depth, were sampled after twelve hours of continuous pumping. Wells Nos. 1 and 2 had radium-226 concentrations of 9.6 and 11 pCi/l respectively, while the following similar chemical characteristics were registered: hardness 374 mg/l, total solids 1,200 mg/l, calcium 88 mg/l, magnesium 40 mg/l and sodium 250 mg/l.

Solids Contact Softening and Filtration

Table 32 lists the concentrations and percentage removals of radium and chemical constituents.

Radium-226

Radium-226 concentration was reduced from an average 9.3 pCi/l in the clarifier No. 1 influent to an average value of 2.6 pCi/l in the clarifier effluent for an average radium removal of 72 percent. One sample collected from the clarifier No. 2 (secondary) effluent receiving a portion of settled No. 1 effluent showed no additional radium removal.

TABLE 32
Radium-226, Hardness, Calcium, and Magnesium Removals
Solids Contact Softeners and Filtration
West Des Moines, Iowa
August 1, 1974

Sampling Point	Radium-226		Hardness		Calcium		Magnesium	
	pCi/l	Percent Removal	Mg/l	Percent Removal	Mg/l	Percent Removal	Mg/l	Percent Removal
Well Supply	9.3		376		88		40	
Clarifier #1 Eff.	2.6	72	215	43	33	62	27	32
Filter Eff.	2.35	10	190	12	31	6	27	0
Overall		75		50		65		35
System	1.9	--	168	--	28	--	26	--

A sand and anthracite filter sampled at 8 hours and 12 hours after backwash showed a slight additional average radium-226 removal to 2.35 pCi/l for an additional 10 percent radium removal by filtration of calcium carbonate and other solids from the clarifier effluent. This filter with the anthracite media for some reason was permitting turbidity to pass through the filter. The 1.9 pCi/l radium concentration shown for the distribution system indicates that other filters may be more efficient or solids are settling in the clear well or other surface storage basins.

An overall radium-226 removal of 75 percent was accomplished by the softening process using lime and a small amount of soda ash.

Hardness

Hardness was reduced from an average of 376 mg/l in the clarifier influent to values of 242 and 188 mg/l in the clarifier No. 1 effluent at 8 hour and 12 hour intervals after starting operation for the day. There is an average unit removal of 43 percent with a maximum removal of 50 percent utilizing the lowest clarifier hardness value. Due to extremely hot weather during the sampling period, water consumption was at a high rate and the solids contact unit flow rates were near the maximum.

The average clarifier effluent hardness value of 215 mg/l was reduced in the filter effluent to 190 mg/l for an additional removal of 12 percent. Clarifier hardness samples collected after the longer operating times indicate little hardness removal was taking place due possibly to turbidity passing through the filter. The overall hardness reduction through all units was 50 percent with a final hardness of 190 mg/l in the filter effluent although the system hardness was 168 mg/l. Calcium decreased from 88 mg/l to the range of 30 mg/l following the lime softening process. Magnesium reduction was from 40 mg/l to 27 mg/l.

RADIUM-226 MATERIAL BALANCE

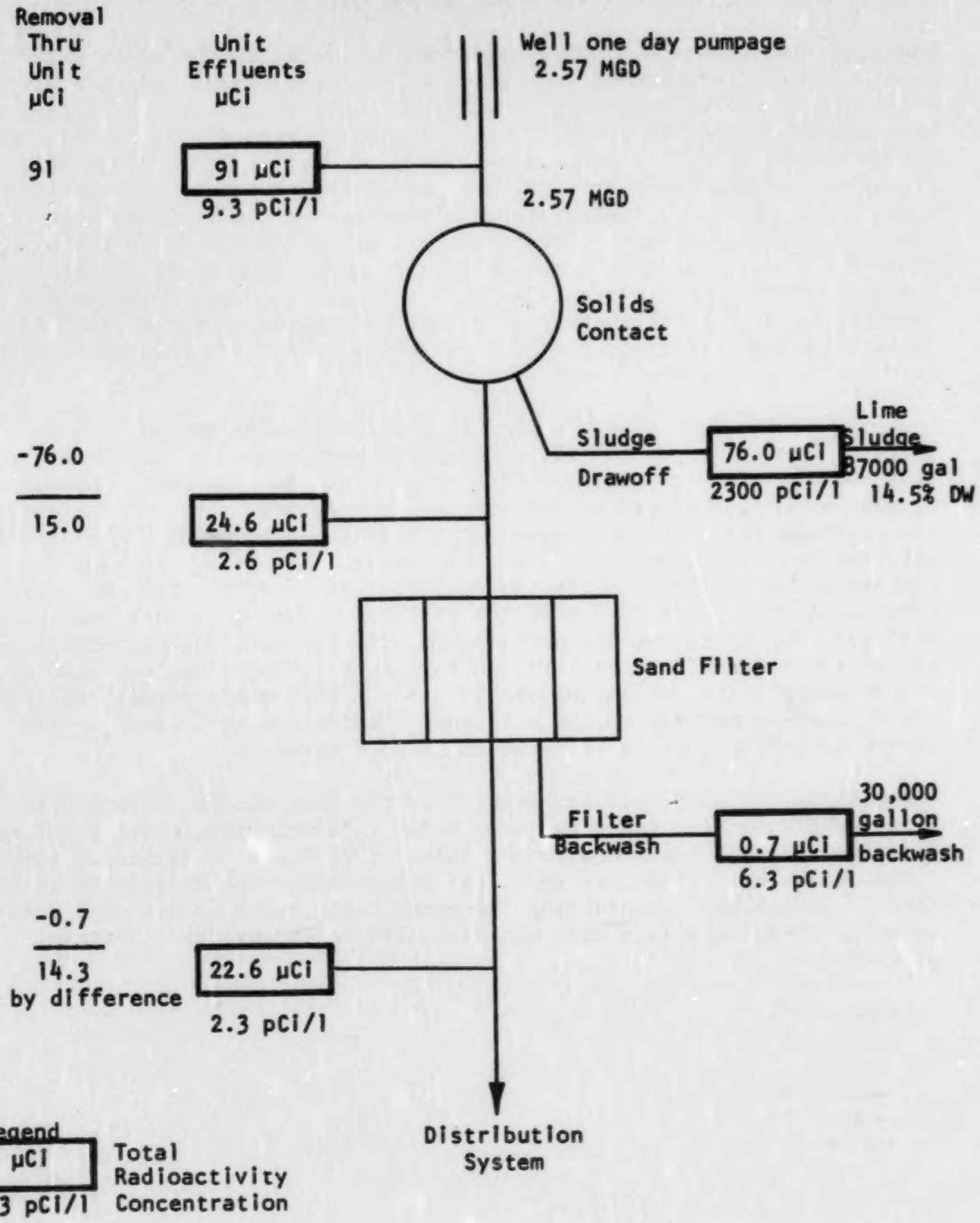
Figure 43 is a schematic drawing showing the process units and the radium-226 radioactivity at various stages in the treatment process. The detailed computations are shown in Appendix B.

Applying the average 9.3 pCi/l concentration value to the daily well pumpage of 2.57 million gallons gives a total radium-226 radioactivity of 91 µCi in the well pumpage. Settling of the coagulated and softened water in the suspended solids contact softeners reduced the radium concentration to 2.6 pCi/l and radioactivity of 24.6 µCi in the clarifier effluent. It was impossible at the time of the survey to accurately measure the timed continuous sludge blowoff. The sludge pumps were replaced at a later date. Consequently, the radioactivity in the sludge drawoff was calculated from the estimated solids removal by the chemical dosages in the softening process. The average 2,300 pCi/l radium-226 concentration in the 14.5 percent dry weight solids sludge applied to the calculated gallons of lime sludge gave a radium-226 radioactivity of 76.0 µCi in the sludge drawoff.

Backwash of the sand filter contained a radium concentration of 6.3 pCi/l which applied to the 1.2 percent backwash quantity for the day produced a radium-226 radioactivity of 0.7 µCi for the daily pumpage. It will be noted the filter backwash radium-226 concentration is very low and apparently little removal of suspended solids from the clarifier effluent was taking place in the sand filter. Likewise, the radium concentration of 2.6 pCi/l in the clarifier effluent was reduced very slightly to 2.3 pCi/l in the filter effluent. This is a poor removal of radioactivity by filtration as compared with the much higher removal in one of the Webster City filters. Unfortunately the filter selected was a dual media filter which apparently has a coarse media permitting turbidity to pass through in the effluent. Radioactivity present in the suspended solids thus is not removed by the filter.

Subtracting the radioactivity removed by the lime sludge drawoff and filter backwash from the total well water radioactivity leaves a difference of 14.3 µCi compared with the value of 22.6 µCi contained in sand filter effluent. Flow lost by filter backwash was not considered in the flow computations. Considering the unavailability of good sludge drawoff flow data, this is a fair material balance through the treatment system.

Figure 43
Ra-226 Distribution in Treatment Process
West Des Moines, Iowa
Lime-Soda Ash Softening Plant


Removal Thru Unit µCi
Unit Effluents µCi
Well one day pumpage 2.57 MGD
91
91 µCi
9.3 pCi/l
2.57 MGD
Solids Contact
Sludge Drawoff
76.0 µCi
2300 pCi/l
Lime Sludge
37000 gal
14.5% DW
-76.0
15.0
24.6 µCi
2.6 pCi/l
Sand Filter
Filter Backwash
0.7 µCi
6.3 pCi/l
30,000 gallon backwash
-0.7
14.3
by difference
22.6 µCi
2.3 pCi/l
Distribution System
Legend
91 µCi
9.3 pCi/l
Total Radioactivity
Concentration

SECTION 14

COSTS OF TREATMENT

COSTING PROCEDURES

The annual cost of operating and maintaining a water treatment facility consists of six components:

Capital Cost Amortization
Operation Labor
Maintenance Labor
Maintenance Materials
Chemicals
Power

The capital cost invested in a water treatment facility is ordinarily amortized over a period of twenty years at a recovery rate sufficient to cover the cost of bond retirement by the owners of the facility. As an example, a capital cost of debt could be retired over a twenty-year period at 6 percent or an annual recovery factor of 0.0726. All equipment costs, construction costs, and engineering are usually combined to give the capital construction cost.

There are no national guidelines as to the level of operational and maintenance labor required for a water treatment plant to produce a safe, potable water on a continuous basis. Such labor costs vary greatly with the type of treatment, necessary operating and laboratory control, competence of designer, age of facility and many others. Maintenance supplies such as equipment parts, laboratory supplies and other expendables depend on the maintenance philosphy of the plant and municipal officials and the level of technical expertise of the operating personnel.

Electrical power requirements vary greatly with initial well pumping and repumping head requirements. Thus a power requirement in terms of kwhr/kgal of treated water would be difficult to calculate. Electric power costs would also be based on local user rates.

Chemical cost for the principal softening chemicals such as salt, lime and soda ash is dependent on the amount and type of hardness. There are also chemicals needed for coagulation, pH adjustment during the softening process, pH adjustment for protective calcium carbonate deposition and disinfection.

It was impossible to obtain accurate data on the construction cost at many municipalities included in the study due to the age of some of the treatment plants or continuing additions and improvements to the treatment process or treatment plant. Some of the treatment plants are over thirty years old and records of treatment plant construction costs are no longer available.

ANNUAL COSTS

Section 11.25 of the Code of Iowa requires an annual report of the financial transactions and balances of the cities and towns in Iowa be furnished to the Auditor of State. Included in this report of municipal finances is a tabulation of the waterworks utility receipts and expenses, with the latter including plant operation and maintenance, distribution operation and maintenance, accounting and collection, debt service, capital outlay, and several miscellaneous items.

From these state auditor reports, the cost of producing water for each year can be calculated. Unfortunately, the capital cost for the individual treatment process cannot be determined readily due to inclusion of water distribution and well costs, accounting and the debt service in addition to the capital outlay costs. Separation of the distribution system and well costs from the municipal records was not practicable in the time period for the study. Tables included in Section C of the Appendix tabulate the total expenses, including plant operation and maintenance, distribution operation and maintenance, accounting and collection, debt service, capital investment and miscellaneous costs of the systems studied. Distribution costs were high in some of the smaller towns due to extensive water main extensions.

Table 33 summarizes a comparison of the total annual capital and operation costs and the plant operation and maintenance costs in ¢/1,000 gal. for one representative year of the three years tabulated on the Tables in the Appendix. This summary shows high annual water costs with a range from a low of 44¢/1,000 gal. for the City of Grinnell to a high of 132¢/1,000 gal. for the Town of Adair. Grinnell is one of the larger cities, but the annual cost for the following year increased to 77¢/1,000 gal. when a capital cost of $317,000 for a new Jordan well was added to the water financing program. The annual cost for Adair reached a high of 143¢/1,000 gal. during one year due to the cost of a water main extension to an industrial area and a housing subdivision.

Suprisingly, the annual costs of the two iron removal plants, Adair and Stuart, were higher than the zeolite softening plants which generally also used iron removal as pretreatment preceeding the ion exchange process. These two plants are among the smallest of the treatment plants and unit costs would be higher in the case of the smaller plants. Figure 44 shows the design plant capacity plotted against the annual and plant operation and maintenance costs in ¢/1,000 gallons. The City of

Table 33

Comparison of Annual Capital and Operation Costs and Plant O&M Cost (1) ¢/1000 gal

Municipality	1970 Population	Treatment	Plant Capacity MGD	Annual Pumpage MG/yr	Total Cost		Range of Costs ¢/1000	O&M Cost	
					Amount	Costs ¢/1000		Amount	Costs ¢/1000
Reverse Osmosis									
Greenfield	2212	RO	0.22	20(2)	$ 46,944	101¢	91-111	$ 4,737	23¢
Iron Removal									
Adair	750	Greensand	0.16	24.5	32,358	132	143(3)	11,243	45
Stuart	1354	Aer-IR	0.43	56.3	40,944	73	64-79	6,726	12
Zeolite Softening									
Eldon	1319	IR-Zeo	0.28	36.9	23,886	65	59-91(4)	10,909	30
Estherville	8108	IR-Zeo	1.2	408	199,614	57	44-66	7,793	26
Grinnell	8402	Aer-Zeo	1.5	416	185,101	44	77(5)	95,737	23
Holstein	1445	IR-Zeo	0.32	51.6	29,112	59	72	17,170	33
Lime Softening									
Webster City	8488	Lime-SA	25	507	269,898	53	53-64	104,613	21
West Des Moines	16441	Lime-SA	35	613	(6)			124,868	20

(1) Based on recent representative year
(2) Reverse Osmosis used to supplement surface water supply
(3) High costs due to water main construction
(4) Capital cost increase due to new salt storage facilities
(5) $317,000 capital cost for new Jordan well
(6) Not tabulated; extreme costs due to plant improvement costs

West Des Moines was not included in the total annual cost in view of an extreme increase in annual costs due to the inclusion of capital cost items for a large plant improvement during this period.

Figure 44 indicates the grouping of the 3 larger cities in the study in the 50-60¢/1,000 gal. annual cost range and the grouping of the smaller plants in the higher 60-132¢/1,000 gal. annual cost range. Major portions of the three larger plants were constructed 20-25 years ago and capitalization costs would be relatively low. Likewise, major portions of all of the other smaller plants, with the exception of the Greenfield reverse osmosis plant, were also constructed 10 or more years ago.

PLANT OPERATION AND MAINTENANCE COSTS

The plant operation and maintenance costs are tabulated in Table 33 and shown in Figure 44. These costs were taken from the representative year data given in the municipal cost data in Section C of the Appendix.

The operation and maintenance (O & M) costs for Greenfield in the 23¢/1,000 gal. range may be low since the plant is located in the basement of the surface water plant and the generally limited need for operating time is handled by the surface water plant operator. Membrane replacement costs over a period of time which are considered maintenance costs are not included in these costs.

The two iron removal plants show the highest and lowest O & M costs of the treatment plants surveyed. Adair has the smallest population and had extensive maintenance on the greensand filter during the period. On the other hand, the Stuart iron removal plant is located adjacent to the power plant and personnel can be used more effectively in the combined systems.

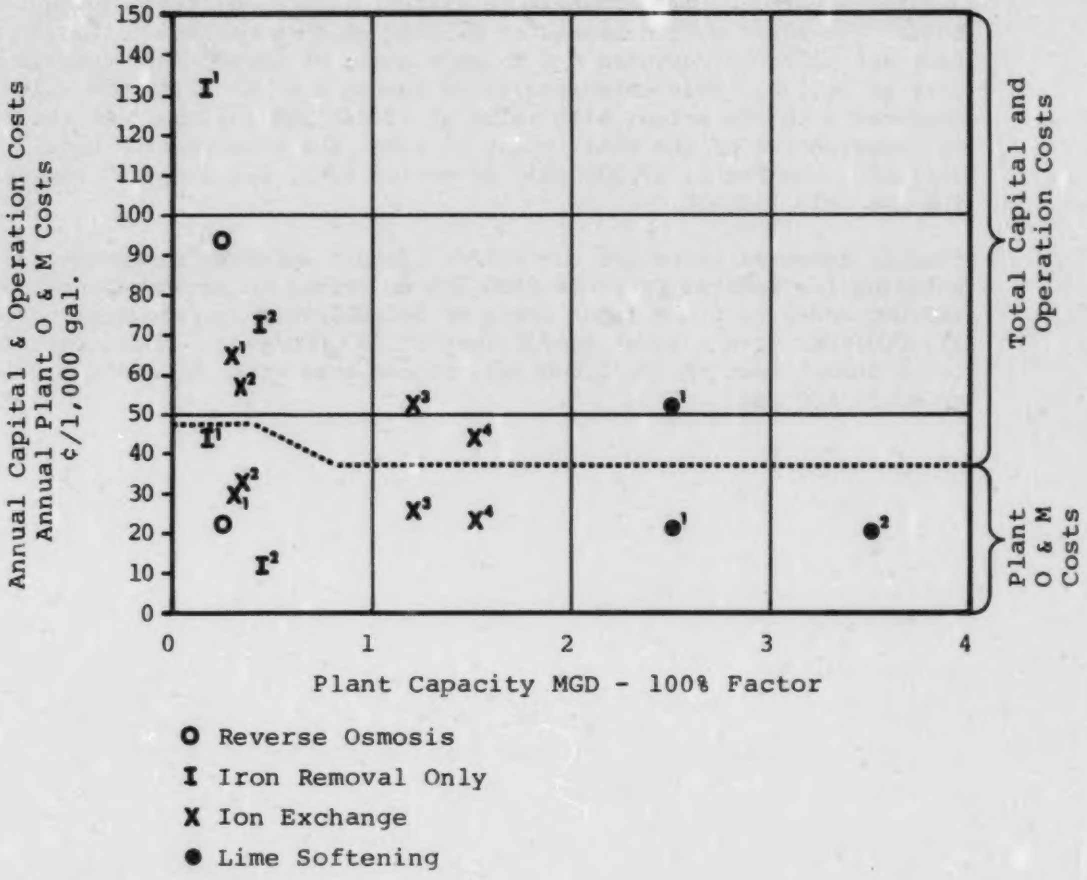
In the zeolite softening plants the two larger plants have the lower O & M cost of 23 and 26¢/1,000 gal. compared with the smaller plant values of 30 and 33¢/1,000 gal. In spite of the higher O & M costs, the smaller plants were not receiving the same degree of good operation and maintenance as the larger plants due to other necessary routine work outside the treatment plant in the smaller towns.

The O & M costs for the lime-soda ash plants were the lowest, being in the 20 to 21¢/1,000 gal. range. Both are in the same range in spite of the larger population for West Des Moines. Maintenance may be lower than normal at Webster City, in view of planning for a new softening plant at a different site.

FIGURE 44

ANNUAL CAPITAL AND OPERATION COSTS

ANNUAL PLANT O & M COSTS



COST COMPARISON

A search of the literature indicated a considerable number of studies showing cost data for plant and operation data for the various types of treatment processes. Attempts were made to correlate replacement costs or operation costs with Iowa data with poor success. Wood[26] reports cost data for lime-soda ash treatment and zeolite softening which indicates that zeolite softening plants are more economical up to a capacity of about 4 mgd and that lime-soda ash plants are more economical above this capacity. However, this data does not include labor costs or pretreatment. Data on cost of ion exchange treatment are reported by Faber,[27] et al. Other studies are also reported by Miller,[28] Bresler and Miller[29] and Mattson[30].

A manual [31] for calculation of costs of conventional water treatment costs was prepared for the Office of Saline Water. Applying the cost graphs and other cost data to two Iowa plants, Adair and Webster City, resulted in much lower computed total costs as compared with the actual auditor reports. The permanganate system, site preparation and building costs for Adair were computed at $43,000 which amortized to $3,750 per year and added to computed O & M labor costs of $3,000 gave total annual cost of $6,750. This converted to an annual cost of 27¢/1,000 gal. compared with the actual high value of 132¢/1,000 gallons. At the time of construction of the Adair plant in 1964, the construction cost, including equipment, 17,000 gal. detention tank, building and engineering was only $17,500.

Similar computed costs for the solids contact softener equipment and building for Webster City was $500,000 amortized to an annual cost of $40,000 added to O & M labor costs of $40,000/year and chemical costs of $15,000/year gave a total annual cost of $95,000/year. This converted to an annual cost of 27¢/1,000 gal. as compared with the auditor report of 65¢/1,000 gal.

SECTION 15

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SECTION 16

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SECTION 17

DEFINITIONS

Alkalinity	Capacity to neutralize acids. In water, most alkalinity is due to the content of bicarbonates, carbonates, or hydroxide. The alkalinity is normally expressed in terms of calcium carbonate equivalents.
Amortization	The uniform annual payment for the prescribed loan period to retire the capital debt obligation. Equal annual payments generally represent declining interest and increasing principal payments over the life of the debt.
Anion	An ionic particle which is negatively charged.
Aquifer	A geologic formation, a group of formations, or a part of a formation that is water-bearing; the term is usually limited to those units capable of yielding water in sufficient quantity to constitute a usable supply.
Backwash	Reverse (normally upwards) flow through a bed of mineral or ion exchange resin to remove insoluble particulates and to loosen the bed.
Bed Depth	The height of mineral or ion exchange resin in a column.
Blending	Mixing of softened water from an ion exchange plant with unsoftened water to obtain a desired hardness content.
Bed Volume	The amount of mineral or ion exchange resin, in a column.
Breakthrough	Refers to the concentration of a particular ion or hardness in the effluent from a treatment system. Breakthrough occurs when the effluent concentration rapidly increases. Normally, when the breakthrough concentration reaches about 10% of the influent concentration, exhaustion has occurred.
Brine	Saturated or diluted solution of salt (NaCl) used in chemical process of replacing sodium ions removed during the ion exchange process.

Capacity	The quantitative ability of a treatment component or system to perform. With ion exchange systems, this quantity is expressed as kilograins per cubic foot.
Cation	An ionic particle which is positively charged.
Composite Sample	A sample collected to be representative of a water flow which continues for an extended period of time.
Curie (Ci)	The unit of quantity of radioactivity, the curie, is defined as 37 billion nuclear transformations per second.
Downflow	Direction of flow of solutions through ion exchange or mineral bed colums during operation; in at the top and out at the bottom.
Endpoint	The achievement of exhaustion. With ion exchange resins, the endpoint of the softening cycle is considered at 10% breakthrough.
Formation	The function of a process component in the service cycle. The regenerated form of a weak base resin without adsorbed acids.
gpg Grains Per Gallon	A unit of concentration (weight per volume) that is used in the ion exchange industry. (See "Grain".) One gpg is numerically equal to 17.1 mg/l.
Grain	A unit of weight, being numerically equal to 1/7000th of a pound. (See "Grains Per Gallon".)
gpcpd	Gallons per capita per day, a measure of water consumption in municipalities.
gpd	Gallons per day.
gpm	Gallons per minute.
gpm/cu ft	Gallons per minute per cubic foot of ion exchange resin or other mineral.
gpm/sq ft	Gallons per minute per square foot of cross-sectional area.
Gross Alpha Particle Activity	This means the total radioactivity due to alpha particle emission.

Hardness	The sum of the calcium and magnesium ions, although other polyvalent cations are included at times. Hardness is normally expressed in terms of calcium carbonate equivalents.
Ion	When salts and minerals are dissolved in water, their atoms take on positive or negative charges and are free to wander in the solution. These charged atoms are called ions. For example, sodium chloride, or common salt, splits into positively charged sodium (cation) and negatively changed chloride (anion) ions.
Ion Exchange Resin	An insoluble material which can remove ions by replacing them with an equivalent amount of a similarly charged ion.
kgr Kilograins	A unit of weight (1,000 grains) equal to 1/17th of a pound.
kgr/cu ft	Kilograins (expressed as calcium carbonate) per cubic foot of ion exchange resin.
Leakage	The amount of unadsorbed ion present in the effluent of a treatment component.
Lime	Lime refers to compounds of calcium. Hydrated lime is calcium hydroxide. Lime which is not hydrated is referred to as quick lime, which is calcium oxide.
Material Balance	Radioactivity input into a treatment system will equal the sum of all output streams when there is no significant accumulation in the system.
mgd	Millions of gallons per day.
Microcurie	The microcurie (one millionth curie) is a unit of quantity of radioactivity used in expressing very low natural or environmental levels (10^{-6} Ci).
mg/l Milligrams Per Liter	A unit of concentration referring to the milligrams weight of a solute per liter of solution. The term is approximately equal to the older "part per million" term.
pCi/l Picocurie Per Liter	The picocurie per liter (one million millionth curie) is a measure of the concentration of radioactivity in a liter of given water (10^{-12} Ci).

Product Water	Output of a desalt or reverse osmosis plant.
Regeneration	Restoration of an ion exchange resin to its desired ionic form by a brine rinse.
Rinse	The removal of chlorides of calcium and magnesium and excess regenerant from an ion exchange resin.
RO	Reverse osmosis demineralization process.
Salometer Degree	Measurement of salinity in brine solution by specific gravity hydrometer with scale of 100 degrees at complete saturation of 26.3% NaCl.
Softening	Removal of the hardness (calcium and magnesium ions) from water.
Total Solids	The number of milligrams per liter of all dissolved and suspended solids in a given water. Equivalent to total residue.
Turbidity	An expression of the optical property of a sample which caused light to be scattered and absorbed rather than transmitted in straight lines through the sample. Turbidity is due to fine visible material in suspension, which may not be of sufficient size to be seen as individual particles by the naked eye but which prevents the passage of light through the liquid.
Unit Cost	Generally expressed in terms of cost in cents per thousand gallons of water. All cost comparisons are related to the unit costs of treated water.
Zeolite Softening	Common expression for ion exchange softenint.

APPENDIX

SECTION A

COMPLETE MINERAL ANALYSIS

Table A-1

COMPLETE MINERAL ANALYSIS - Greenfield

Date	8-8-74	8-8-74	8-8-74
Source	Well #1	RO Plant	RO Reject
Sampling Data	5hrs	@ 5hrs	#1@5 hrs
ANALYSIS (Miligrams per liter)			
Specific Conductance microhms @25°C	3000	300	7800
pH	7.8	5.9	
Total Residue	2150	159	6470
Filtrable Residue	2150	159	6470
Alkalinity as $CaCO_3$ P	0	none	none
T	190	44.0	46.0
Hardness as $CaCO_3$	630	40.0	1840
Total Iron	1.6	0.03	4.1
Soluble Iron	1.6	0.03	4.1
Silica ($Si\ O_2$)	13	0.8	5.8
Positive Ions			
Potassium	25	3.0	86
Sodium	440	55	1300
Calcium	160	6.7	480
Magnesium	54	2.3	160
Manganese	< 0.01	< 0.01	0.01
Negative Ions			
Nitrate	< 0.1	< 0.1	*Note
Fluoride	2.8	1.2	6.0
Chloride	395	40	1200
Sulfate	870	50	2900
Bicarbonate	232	53.7	56.1
Carbonate	none	none	None
Trace Metals			
Arsenic	< 0.01	< 0.01	< 0.01
Barium	< 0.1	< 0.1	< 0.1
Cadmium	< 0.01	< 0.01	< 0.01
Chromium	0.01	< 0.01	< 0.01
Copper	0.01	0.19	0.02
Lead	< 0.01	< 0.01	0.01
Zinc	0.05	0.12	0.02
Mercury µg/l	< 1	< 1	< 1
Silver	< 0.01	< 0.01	< 0.01
Radioactivity (picocuries/L)			
Gross Alpha	21	nil	86
Radium-226	14	0.5	38

*Because of extremely high chloride, unable to report NO_3.

Table A-2

COMPLETE MINERAL ANALYSIS-ADAIR

Date	9-16-74	9-17-74	9-16-74	9-18-74
Source	Well #3	Filter Inf	Filter Eff	Filter Eff
Sampling Data	6hr 190gpm	6hrs	25,000 gal	BW 2Min
ANALYSIS (Miligrams per liter)				
Specific Conductance microhms @25°C	2600	2700	2700	2600
pH	7.5	7.45	7.45	7.4
Total Residue	1921	1886	1896	2057
Filtrable Residue	1905	1851	1891	1900
Alkalinity as $CaCO_3$ P	None	None	None	None
T	158	161	164	163
Hardness as $CaCO_3$	710	710	700	710
Total Iron	0.58	0.10	0.17	64
Soluble Iron	0.04	0.01	0.01	0.21
Silica ($Si\ O_2$)	8.6	9.8	9.4	*34
Positive Ions				
Potassium	40	39	42	39
Sodium	330	330	330	330
Calcium	180	170	180	170
Magnesium	70	70	66	70
Manganese	0.01	0.01	0.01	3.1
Negative Ions				
Nitrate	5.5	7.2	6.1	7.4
Fluoride	2.8	2.3	2.2	2.0
Chloride	330	360	350	370
Sulfate	780	760	760	770
Bicarbonate	200	196	193	199
Carbonate	none	None	None	None
Trace Metals				
Arsenic	< 0.01	< 0.01	< 0.01	< 0.01
Barium	< 0.1	< 0.1	< 0.1	< 0.1
Cadmium	< 0.01	< 0.01	< 0.01	< 0.01
Chromium	< 0.01	< 0.01	< 0.01	< 0.01
Copper	< 0.01	< 0.01	0.01	0.02
Lead	< 0.01	< 0.01	< 0.01	< 0.01
Zinc	0.07	0.02	0.16	0.97
Mercury µg/l	< 1	< 1	< 1	< 1
Silver	< 0.01	< 0.01	< 0.01	< 0.01
Radioactivity (picocuries/L)				
Gross Alpha	16	6.8	10	330
Radium-226	6.3	6.9	7.7	250

Iron results are expected to be higher than correct results since sample was collected in bottle with an iron cap.

*Lab. Note--Silica could be in error due to high iron value

Table A-3

COMPLETE MINERAL ANALYSIS - Stuart

Date	10-22-74	10-22-74	10-22-74
Source	Well #3	Filter BW	Dist System
Sampling Data	5hrs 300gpm	@ 2min	Amoco Sta
ANALYSIS (Miligrams per liter)			
Specific Conductance microhms @25^{o}C	2500	2500	2500
pH	7.6	7.6	7.65
Total Residue	1770	2178	1740
Filtrable Residue	1770	1748	1740
Alkalinity as $CaCO_3$ P	None	None	None
T	182	186	170
Hardness as $CaCO_3$	640	630	620
Total Iron	0.94	120	0.22
Soluble Iron	0.94	120	0.22
Silica ($Si\ O_2$)	10	56	10
Positive Ions			
Potassium	38	35	35
Sodium	310	310	310
Calcium	150	160	150
Magnesium	62	62	62
Manganese	<0.01	0.23	<0.01
Negative Ions			
Nitrate	1.5	7.6	5.2
Fluoride	2.6	3.1	2.8
Chloride	240	260	250
Sulfate	780	790	780
Bicarbonate	222	227	207
Carbonate	None	None	None
Trace Metals			
Arsenic	<0.01	<0.01	<0.01
Barium	< 0.1	< 0.1	< 0.1
Cadmium	<0.01	<0.01	<0.01
Chromium	<0.01	<0.01	<0.01
Copper	<0.01	0.03	0.03
Lead	<0.01	<0.01	<0.01
Zinc	<0.01	0.04	0.01
Mercury µg/l	< 1	1.6	< 1
Silver	<0.01	<0.01	<0.01
Radioactivity (picocuries/L)			
Gross Alpha	32	340	23
Radium-226	16	230	12

Table A-4

COMPLETE MINERAL ANALYSIS - Eldon

Date	9-11-74	9-12-74	9-12-74	9-11-74
Source	Well #8	IR Filter	#1 Exchanger	IR Filter
Sampling Data	6hrs 250gpm	Eff 12hr	@ 40,000	BW 2min
ANALYSIS (Miligrams per liter)				
Specific Conductance microhms @25°C	1900	1900	2000	1900
pH	7.5	7.85	8.0	7.6
Total Residue	1228	1218	1350	1703
Filtrable Residue	1228	1209	1316	1234
Alkalinity as $CaCO_3$ P	None	None	None	None
T	252	247	241	246
Hardness as $CaCO_3$	400	380	8.0	370
Total Iron	1.9	0.51	0.11	230
Soluble Iron	1.9	0.51	0.11	230
Silica (SiO_2)	9.8	10	9.2	66
Positive Ions				
Potassium	22	37	6.0	37
Sodium	280	280	430	280
Calcium	82	83	2.3	94
Magnesium	37	37	0.9	38
Manganese	0.01	0.01	0.01	0.86
Negative Ions				
Nitrate	1.0	3.6	6.4	7.7
Fluoride	1.5	1.8	1.8	1.8
Chloride	160	160	160	170
Sulfate	490	490	500	500
Bicarbonate	307	301	294	300
Carbonate	None	None	None	None
Trace Metals				
Arsenic	<0.01	<0.01	<0.01	0.01
Barium	< 0.1	< 0.1	< 0.1	0.1
Cadmium	<0.01	<0.01	<0.01	<0.01
Chromium	<0.01	<0.01	<0.01	<0.01
Copper	0.02	0.01	0.04	0.01
Lead	<0.01	<0.01	<0.01	<0.01
Zinc	<0.01	<0.01	0.04	0.08
Mercury µg/l	< 1	< 1	< 1	< 1
Silver	<0.01	<0.01	<0.01	<0.01
Radioactivity (picocuries/L)				
Gross Alpha	53	74	5.6	1540
Radium-226	50	44	1.3	1027

Iron result may be higher because sample was collected in bottle with an iron cap.

*Nitrate could not be analyzed due to extreme chloride interference.

Trace metals may be in error due to extreme chloride interference.

Table A-4 (cont.)

COMPLETE MINERAL ANALYSIS - Eldon

Date	9-13-74
Source	Brine Rinse
Sampling Data	30min
ANALYSIS (Miligrams per liter)	
Specific Conductance microhms @25°C	86,000
pH	6.4
Total Residue	88,372
Filtrable Residue	88,362
Alkalinity as $CaCO_3$ P	None
T	126
Hardness as $CaCO_3$	27,000
Total Iron	0.54
Soluble Iron	0.54
Silica ($Si\ O_2$)	9.4
Positive Ions	
Potassium	104
Sodium	14,800
Calcium	6,000
Magnesium	2,600
Manganese	0.17
Negative Ions	
Nitrate	*
Fluoride	0.4
Chloride	41,000
Sulfate	1,100
Bicarbonate	154
Carbonate	None
Trace Metals	
Arsenic	< 0.01
Barium	1.4
Cadmium	< 0.01
Chromium	< 0.01
Copper	0.08
Lead	< 0.1
Zinc	0.05
Mercury µg/l	< 1
Silver	< 0.01
Radioactivity (picocuries/L)	
Gross Alpha	4,000
Radium-226	3,500

Iron result may be higher because sample was collected in bottle with an iron cap.

*Nitrate could not be analyzed due to extreme chloride interference.

Trace metals may be in error due to extreme chloride interference.

Table A-5

COMPLETE MINERAL ANALYSIS - Estherville

Date	10-8-74	10-8-74	10-9-74	10-9-74
Source	Well #8	IR Filter	#3 Exchanger	Blended
Sampling Data	6hr 800gpm	EFF 30 day	Eff 50%	Eff 10hr
ANALYSIS (Miligrams per liter)				
Specific Conductance microhms @25°C	1700	1600	2000	2000
pH	7.1	7.7	7.5	7.6
Total Residue	1350	1360	1360	1370
Filtrable Residue	1350	1360	1360	1370
Alkalinity as $CaCO_3$ P	None	None	None	None
T	367	372	386	398
Hardness as $CaCO_3$	915	915	36.0	48.0
Total Iron	1.6	2.8	0.08	0.10
Soluble Iron	1.6	2.8	0.08	0.10
Silica ($Si\ O_2$)	20	20	16	15
Positive Ions				
Potassium	7.5	7.6	3.5	3.8
Sodium	59	55	420	420
Calcium	240	240	11	13
Magnesium	83	83	4.1	3.8
Manganese	0.24	0.27	< 0.01	0.01
Negative Ions				
Nitrate	< 0.1	14	5.7	7.4
Fluoride	0.25	0.3	0.7	0.75
Chloride	3	2	3	9.5
Sulfate	670	670	630	630
Bicarbonate	448	354	471	486
Carbonate	None	None	None	None
Trace Metals				
Arsenic	< 0.01	<0.01	< 0.01	<0.01
Barium	< 0.1	< 0.1	< 0.1	< 0.1
Cadmium	< 0.01	<0.01	< 0.01	<0.01
Chromium	< 0.01	<0.01	< 0.01	<0.01
Copper	< 0.01	<0.01	< 0.01	<0.01
Lead	< 0.01	<0.01	< 0.01	<0.01
Zinc	< 0.01	<0.01	< 0.01	0.02
Mercury µg/l	< 1	< 1	< 1	< 1
Silver	< 0.01	<0.01	< 0.01	<0.02
Radioactivity (picocuries/L)				
Gross Alpha	5.5	16	3.3	1.4
Radium-226	5.2	8.1	0.1	0.5

Table A-5 (cont.)

COMPLETE MINERAL ANALYSIS - Estherville

Date	10-9-74
Source	Brine Rinse
Sampling Data	15 min
ANALYSIS (Miligrams per liter)	
Specific Conductance microhms @25°C	48,000
pH	6.9
Total Residue	48,900
Filtrable Residue	48,900
Alkalinity as $CaCO_3$ P	None
T	546
Hardness as $CaCO_3$	10,800
Total Iron	0.34
Soluble Iron	0.34
Silica (SiO_2)	20
Positive Ions	
Potassium	140
Sodium	13,000
Calcium	3,100
Magnesium	820
Manganese	0.78
Negative Ions	
Nitrate	*
Fluoride	0.9
Chloride	26,000
Sulfate	1,400
Bicarbonate	666
Carbonate	None
Trace Metals	
Arsenic	
Barium	
Cadmium	
Chromium	
Copper	
Lead	
Zinc	
Mercury	
Silver	
Radioactivity (picocuries/L)	
Gross Alpha	128
Radium-226	52

*Due to high chloride interference nitrate could not be analyzed.
No metals analysis.

Table A-6

COMPLETE MINERAL ANALYSIS - Grinnell

Date	8-18-74	8-18-74	8-18-74	8-18-74
Source	Well #5	Well #6	Well #7	Exchanger
Sampling Data	4hrs 460 gpm	4 hr 500gpm	3hr 690gpm	#2 Inf 4 hr
ANALYSIS (Miligrams per liter)				
Specific Conductance microhms @25°C	1100	1300	1100	1200
pH	7.35	7.3	7.3	7.55
Total Residue	784	922	742	822
Filtrable Residue	784	922	742	822
Alkalinity as $CaCO_3$ P	None	None	None	None
T	298	334	263	290
Hardness as $CaCO_3$	368	420	368	384
Total Iron	1.1	0.26	0.76	0.41
Soluble Iron	1.1	0.26	0.76	0.41
Silica ($Si\ O_2$)	8.8	8.4	8.4	9.0
Positive Ions				
Potassium	16	19	15	16
Sodium	110	130	95	120
Calcium	82	98	82	88
Magnesium	43	46	44	44
Manganese	0.01	0.01	0.01	0.01
Negative Ions				
Nitrate	<0.1	<0.1	<0.1	2.2
Fluoride	1.2	1.2	1.2	1.2
Chloride	18	24	16	22
Sulfate	320	380	290	340
Bicarbonate	364	407	321	354
Carbonate	None	None	None	None
Trace Metals				
Arsenic	<0.01	<0.01	<0.01	<0.01
Barium	<0.1	<0.1	<0.1	<0.1
Cadmium	<0.01	<0.01	<0.01	<0.01
Chromium	<0.01	<0.01	<0.01	<0.01
Copper	<0.01	<0.01	<0.01	<0.01
Lead	<0.01	<0.01	<0.01	<0.01
Zinc	<0.01	<0.01	<0.01	<0.01
Mercury	<1 μg/l	<1 μg/l	<1 μg/l	3 μg/l
Silver	<0.01	<0.01	<0.01	<0.01
Radioactivity (picocuries/L)				
Gross Alpha	14	23	5.4	12
Radium-226	6.2	7.2	4.1	5.6

Table A-6 (cont.)

COMPLETE MINERAL ANALYSIS - Grinnell

Date	7-18-74	7-18-74	10-31-74
Source	Exchanger	Blended	Brine Rinse
Sampling Data	#2 Eff 50%	Eff 1 hr	30 Min
ANALYSIS (Miligrams per liter)			
Specific Conductance microhms @25°C	1300	1300	81,700
pH	7.7	8.65	7.0
Total Residue	860	880	56,400
Filtrable Residue	860	880	56,400
Alkalinity as $CaCO_3$ P	None	17.0	None
T	292	328	264
Hardness as $CaCO_3$	6.0	100	19,800
Total Iron	0.03	0.14	0.25
Soluble Iron	0.03	0.14	0.25
Silica ($Si\ O_2$)	7.4	8.2	10
Positive Ions			
Potassium	0.8	16	440
Sodium	290	260	11,000
Calcium	2.4	21	5,120
Magnesium	0.5	11	1,700
Manganese	0.01	0.01	0
Negative Ions			
Nitrate	0.1	0.45	*
Fluoride	1.3	1.3	0.8
Chloride	21	21	32,000
Sulfate	330	330	900
Bicarbonate	356	359	322
Carbonate	None	20.4	None
Trace Metals			
Arsenic	< 0.01	< 0.01	
Barium	< 0.1	< 0.1	
Cadmium	< 0.01	< 0.01	
Chromium	< 0.01	< 0.01	
Copper	< 0.01	< 0.01	
Lead	< 0.01	< 0.01	
Zinc	< 0.01	< 0.01	
Mercury μg/l	< 1	< 1	
Silver	< 0.01	< 0.01	
Radioactivity (picocuries/L)			
Gross Alpha	1.7	2.5	470
Radium-226	0.2	1.4	290

*Due to high chloride interferences nitrate could not be analyzed.

No metals analysis.

Table A-7

COMPLETE MINERAL ANALYSIS - Holstein

Date	11-24-74	11-24-74	11-24-74	11-29-74
Source	Well #1	Aerator	IR Filter	Exchanger
Sampling Data	4hr 220gpm	Eff 5hr	Eff 1 wk	Eff 25,000
ANALYSIS (Milligrams per liter)				
Specific Conductance microhms @25°C	1800	1800	1800	2200
pH	7.1	7.6	7.35	7.45
Total Residue	1510	1510	1500	1490
Filtrable Residue	1510	1510	1500	1490
Alkalinity as $CaCO_3$ P	None	None	None	None
T	288	290	284	276
Hardness as $CaCO_3$	920	870	880	15.0
Total Iron	1.8	1.6	0.09	0.03
Soluble Iron	1.8	1.6	0.09	0.03
Silica ($Si\ O_2$)	9.0	9.0	9.0	11
Positive Ions				
Potassium	11	11	11	4.7
Sodium	110	110	110	510
Calcium	240	240	240	4.0
Magnesium	69	69	69	1.3
Manganese	0.15	0.14	0.01	0.01
Negative Ions				
Nitrate	0.2	1.1	5.2	3.1
Fluoride	0.85	0.85	0.85	0.85
Chloride	7	7	8	10
Sulfate	800	790	790	790
Bicarbonate	351	354	346	337
Carbonate	None	None	None	None
Trace Metals				
Arsenic	<0.01	<0.01	<0.01	<0.01
Barium	<0.1	<0.1	<0.1	<0.1
Cadmium	<0.01	<0.01	<0.01	<0.01
Chromium	<0.01	<0.01	<0.01	<0.01
Copper	<0.01	<0.01	<0.01	<0.01
Lead	<0.01	<0.01	<0.01	
Zinc	<0.01	<0.01	<0.01	0.02
Mercury µg/l	< 1	< 1	< 1	< 1
Silver	<0.01	<0.01	<0.01	<0.01
Radioactivity (picocuries/L)				
Gross Alpha	26	32	32	1.9
Radium-226	14	10	7.3	0.4

Table A-7 (cont.)

COMPLETE MINERAL ANALYSIS - Holstein

Date	10-29-74
Source	Brine Rinse
Sampling Data	10 min
ANALYSIS (Miligrams per liter)	
Specific Conductance microhms @25^oC	185,000
pH	6.0
Total Residue	166,000
Filtrable Residue	166,000
Alkalinity as $CaCO_3$ P	None
T	98.0
Hardness as $CaCO_3$	78,000
Total Iron	0.78
Soluble Iron	0.78
Silica ($Si\ O_2$)	10
Positive Ions	
Potassium	650
Sodium	19,000
Calcium	20,000
Magnesium	5,000
Manganese	2.7
Negative Ions	
Nitrate	*
Fluoride	0.85
Chloride	73,000
Sulfate	1,200
Bicarbonate	120
Carbonate	None
Trace Metals	
Arsenic	<0.01
Barium	0.2
Cadmium	<0.01
Chromium	<0.01
Copper	<0.01
Lead	
Zinc	0.04
Mercury µg/l	< 1
Silver	<0.01
Radioactivity (picocuries/L)	
Gross Alpha	1,700
Radium-226	700

*Due to high chloride unable to make nitrate analysis. Heavy metal results may be in error due to high salt content which causes interferences in analysis.

Table A-8

COMPLETE MINERAL ANALYSIS - Webster City

Date	8-13-74	8-13-74	8-13-74
Source	Well #5	Aerator	Filter #4
Sampling Data	6hr 950gpm	Eff 5hr	Eff 5hr
ANALYSIS (Miligrams per liter)			
Specific Conductance microhms @25°C	1400	1400	1100
pH	7.3	7.75	9.3
Total Residue	1010	971	746
Filtrable Residue	1010	971	746
Alkalinity as $CaCO_3$ P	None	None	32.0
T	294	296	84.0
Hardness as $CaCO_3$	530	510	264
Total Iron	0.69	0.64	0.02
Soluble Iron	0.69	0.64	0.02
Silica ($Si O_2$)	3.6	8.2	8.0
Positive Ions			
Potassium	18	16	15
Sodium	130	120	110
Calcium	110	110	39
Magnesium	48	50	44
Manganese	<0.01	<0.01	<0.01
Negative Ions			
Nitrate	1.7	1.7	1.9
Fluoride	1.3	1.0	1.0
Chloride	71	65	62
Sulfate	380	390	370
Bicarbonate	359	361	24.4
Carbonate	None	None	38.6
Trace Metals			
Arsenic	< 0.01	<0.01	<0.01
Barium	< 0.1	< 0.1	< 0.1
Cadmium	< 0.01	<0.01	<0.01
Chromium	< 0.01	<0.01	<0.01
Copper	0.01	<0.01	0.01
Lead	< 0.01	<0.01	<0.01
Zinc	< 0.01	<0.01	0.57
Mercury µg/l	< 1	< 1	< 1
Silver	< 0.01	<0.01	<0.01
Radioactivity (picocuries/L)			
Gross Alpha	14	20	3.6
Radium-226	7.1	6.8	0.9

Table A-9

COMPLETE MINERAL ANALYSIS - West Des Moines

Date	8-1-74	8-1-74	8-1-74	8-1-74
Source	Well #1	Well #2	Clarifier	Clarifier
Sampling Data	12hr 1200gpm	12hr 1200gpm	Inf 12hr	Eff 12 hr
ANALYSIS (Miligrams per liter)				
Specific Conductance microhms @25°C	1700	1700	1700	1500
pH	7.4	7.5	8.0	10.4
Total Residue	1200	1200	1180	1030
Filtrable Residue	1200	1200	1180	1030
Alkalinity as $CaCO_3$ P	None	None	None	56.0
T	260	258	260	80.0
Hardness as $CaCO_3$	376	372	376	188
Total Iron	0.36	0.33	0.25	0.03
Soluble Iron	0.36	0.33	0.25	0.03
Silica ($Si O_2$)	10	10	9.6	7.8
Positive Ions				
Potassium	18	18	18	18
Sodium	250	250	250	260
Calcium	87	88	88	33
Magnesium	40	40	40	27
Manganese	<0.01	< 0.01	< 0.01	< 0.01
Negative Ions				
Nitrate	<0.1	< 0.1	0.9	0.8
Fluoride	2.2	2.4	2.4	1.9
Chloride	65	67	65	66
Sulfate	550	570	570	580
Bicarbonate	317	315	317	None
Carbonate	None	None	None	14.4
Trace Metals				
Arsenic	< 0.01	< 0.01	< 0.01	< 0.01
Barium	< 0.1	< 0.1	< 0.1	< 0.1
Cadmium	< 0.01	< 0.01	< 0.01	< 0.01
Chromium	< 0.01	< 0.01	< 0.01	< 0.01
Copper	< 0.01	< 0.01	< 0.01	< 0.01
Lead	< 0.01	< 0.01	< 0.01	< 0.01
Zinc	< 0.01	< 0.01	< 0.01	< 0.01
Mercury µg/l	< 1	< 1	< 1	< 1
Silver	< 0.01	< 0.01	< 0.01	< 0.01
Radioactivity (picocuries/L)				
Gross Alpha	26	24	29	7.3
Radium-226	9.6	11	10	2.6

Table A-9 (cont.)

COMPLETE MINERAL ANALYSIS - West Des Moines

Date	8-1-75
Source	Filter
Sampling Data	Eff 12hr
ANALYSIS (Miligrams per liter)	
Specific Conductance microhms @25°C	1500
pH	9.5
Total Residue	1010
Filtrable Residue	1010
Alkalinity as $CaCO_3$ P	30.0
T	90.0
Hardness as $CaCO_3$	192
Total Iron	< 0.01
Soluble Iron	< 0.01
Silica ($Si\ O_2$)	7.8
Positive Ions	
Potassium	18
Sodium	240
Calcium	31
Magnesium	27
Manganese	< 0.01
Negative Ions	
Nitrate	0.6
Fluoride	1.9
Chloride	68
Sulfate	590
Bicarbonate	36.6
Carbonate	36.0
Trace Metals	
Arsenic	< 0.01
Barium	< 0.1
Cadmium	< 0.01
Chromium	< 0.01
Copper	< 0.01
Lead	< 0.01
Zinc	< 0.01
Mercury µg/l	< 1
Silver	< 0.01
Radioactivity (picocuries/L)	
Gross Alpha	8.1
Radium-226	2.3

APPENDIX

SECTION B

RADIUM-226 DISTRIBUTION COMPUTATION

Table B-1

Radium-226 Distribution in Treatment Process
Greenfield, Iowa
Reverse Osmosis Desalting Plant
August 8, 1974

Ra-226 content in well water supplied

144,090 gallons including 69% finished water and 31% reject to waste

144,090 gallons x 3.785 x 14pCi/l x 10^{-6} = 7.62 µCi

Ra-226 accumulation in 45, 370 gallons reject water (31%)

45,370 gallons x 3.785 x 43pCi/l x 10^{-6} = 7.40 µCi

% reject water 45,370 ÷ 144,090 = 31%

Ra-226 remaining in permeator product (plant effluent)(69%)

98,720 gal. x 3.785 x 0.6pCi/l x 10^{-6} = 0.22 µCi

% product water 98,720 ÷ 144,090 = 69%

Table B-2

Radium-226 Distribution in Treatment Process
Adair, Iowa
Greensand iron Removal Plant
September 8, 1974

Ra-226 content in well water supplied 2 days

212,000 gallon pumpage during period

212,000 gallons × 3.785 × 6.6 pCi/l × 10^{-6} = 5.3 μCi

Ra-226 content in influent to greensand filters

No reduction thru 2 hr. detention tank

212,000 gallons × 3.785 × 6.6 pCi/l × 10^{-6} = 5.3 μCi

Ra-226 content in greensand filter backwash

Three samples collected over 8 min. period

Total 3,190 gallons backwash from both filters

3,190 gallon × 3.785 × composite pCi/l × 10^{-6} = 1.2 μCi

Ra-226 content in effluent from greensand filters

Four samples collected over period of operation

212,000 gallons × 3.785 × 6.3 (composite) pCi/l × 10^{-6} = 5.0 μCi

Table B-3
Radium-226 Distribution in Treatment Process
Adair, Iowa
Greensand Iron Removal Plant
May 13, 1975

Ra-226 content in aerated well water influent to greensand filters

8 hrs. pumping at 115 gpm rate

No reduction thru settling

55,200 gallons x 3.785 x 13 pCi/l x 10^{-6} = 2.72 µCi

Ra-226 content in greensand filter backwash

Five sample composite collected over 20 min. period

150,470 gallons filtered before backwash

Total 2,710 gallons backwash from filter

2,710 gallon x 3.785 x 200 (composite) pCi/l x 10^{-6} = 2.05 µCi

Prorated to 55,200 gallon filter effluent flow

2.05 µCi x 55,200 ÷ 150,470 = 0.75 µCi

Ra-226 content in effluent from greensand filters

Four samples collected over period of operation

55,200 gallons x 3.785 x 8 (composite) pCi/l x 10^{-6} = 1.67 µCi

Table B-4

Radium-226 Distribution in Treatment Process
Stuart, Iowa
Pressure Iron Removal Filters
October 22, 1974

Ra-226 content in well water supplied before backwash

of filter at end of two week period

1,970,000 gallons x 3.785 x 16 pCi/l x 10^{-6} = 119 µCi

Ra-226 content in settling tank effluent

Collected at 5 and 20 hours after settling

1,970,000 gallons x 3.785 x 14 pCi/l x 10^{-6} = 104 µCi

Ra-226 content in iron removal backwash

14min. composite of 4 samples

300 gpm @ 14 min. 4200 gal x 4 filters = 16,800 gallons

16,800 gallons x 3.785 x composite 120 pCi/l x 10^{-6} = 7.6 µCi

Ra-226 content in iron removal filter effluent

Collected @ 2 hrs. after backwash and just prior to backwash

1,970,000 gallons x 3.785 x 12 pCi/l x 10^{-6} = 89 µCi

Table B-5

Radium-226 Distribution in Treatment Process
Eldon, Iowa
Iron Removal and Zeolite Softening
September 13, 1974

Iron removal filter backwashed after two week interval

Water pumped during period 1,340,000 gallons (from operation reports)

including zeolite softener backwash and regeneration

Ra-226 content in well water pumped 14 day period

$1.34 \text{ mg} \times 3.785 \times 49 \text{ pCi/l} \times 10^{-6} = 249\ \mu\text{Ci}$

249 μCi ÷ 15 regenerations = 16.6 μCi/regeneration

Ra-226 content removed by iron filter backwash - 4 units

8 minutes at 280 gpm

280 gpm x 8 min x 3.785 x 636 (composite) pCi/l = 5.98 μCi

Total four units 4 x 5.98 μCi = 24.0 μCi

Activity per regeneration cycle 24.0 ÷ 15 = 1.6 μCi

Ra-226 remaining in iron removal effluent

13 mg (2 week period) x 3.785 x 43 pCi/l = 218 μCi

Activity per regeneration cycle 218 ÷ 15 = 14.5 μCi

Ra-226 content removed by zeolite softener backwash

22 min wash @ 90 gpm per regeneration

2000 gal x 3.785 x 30 (composite) pCi/l = 0.23 μCi

Ra- 226 content removed by zeolite softener rinse

60 gpm rinse for 40 min during spent brine discharge

60 gpm x 40 min x 3.785 x 1960 (composite) pCi/l = 17.8 μCi

Reduced activity to 80,000 gal regeneration as compared with 101,000 gal actual regeneration is 14.1 μCi/regeneration

Ra-226 content remaining in zeolite softener effluent

80,000 gal x 3.785 x 43 pCi/l = 0.58 μCi

Table B-6

Radium-226 Distribution in Treatment Process
Estherville, Iowa
Iron Removal and Zeolite Softener Plant
October 8, 1974

Ra-226 content in well water supplied before backwash

of iron removal filter at end of 30 day period.

26.2 mg pumpage during period ÷ 144,000 gal. cycle - 182 cycles

26.2 mg x 3.785 x 5.7 pCi/l x 10^{-6} = 565 μCi

Ra-226 removal by iron removal filter backwash after 30 days.

Backwash water used 86,400 gal.

86,400 gal. x 3.785 x 165(composite) pCi/l x 10^{-6} = 54 μCi

Radioactivity per cycle ÷ 182 = 0.30 μCi/softener cycle

Ra-226 content in zeolite softener influent during one cycle.

130,000 gal. x 3.785 x 5.1 pCi/l x 10^{-6} = 2.51 μCi/softener cycle

Ra-226 removed by zeolite softener backwash

10 minute backwash at 315 gpm = 3150 gal.

3,150 gal. x 3.785 x 94(composite) pCi/l x 10^{-6} = 1.12 μ/Ci

Ra-226 removed by zeolite softener brine rinse

247gpm @ 20 minutes

4,940 gal. x 3.785 x 114 (composite)pCi/l x 10^{-6} = 2.13 μCi

Ra-226 content in zeolite softener effluent

130,000 gal. x 3.785 x 0.3 pCi/l x 10^{-6} = 0.15 μCi

Table B-7

Radium-226 Distribution in Treatment Process

Grinnell, Iowa

Aeration, Settling and Zeolize Softening Plant

July 8, 1974

Ra-226 content in well water for one softener regeneration

216,000 gal x 3,785 x 6.7 pCi/l x10^{-6} = 5.46 μCi

Ra-226 content in settling tank effluent

216,000 gal x 3,785 x 5.7 pCi/l x 10^{-6} =4.66 μCi

Ra-226 removed by zeolite softener backwash

Metered 6,000 gal x 3.785 x 12(composite) pCi/l x 10^{-6} =0.27 μCi

Ra-226 removed by zeolite brine rinse

4700 gal over 60 minute period

4700 gal x3.785 x 232(composite) pCi/l x 10^{-6} = 4.12 μCi

Table B-8

Radium-226 Distribution in Treatment Process
Holstein, Iowa
Pressure Iron Removal and Zeolite Softener
October 24 & 29 - 1974

Ra-226 content in well water supplied before backwash of iron

removal filter at end of weekly period

1,092,000 gal. x 3.785 x 13 pCi/1 x 10^{-6} = 53.7 μCi

Assume 1/14 of this flow (76,000 gal.) and radioactivity

proportional to one softening cycle of zeolite softener

Week's radioactivity 53.7 μCi ÷ 14 = 3.83 μCi/cycle

Ra-226 remaining in detention tank effluent (2 hr. dention)

Collected 6 hrs. after start of well pumping

1,092,000 gal. x 3.785 x 10 pCi/1 x 10^{-6} ÷ 14 cycles = 2.94 μCi

Ra-226 remaining in iron filter effluent

Collected at 3 days and 7 days

70,000 I gal. x 3.785 x 7.2 pCi/1 x 10^{-6} = 1.91 μCi

Ra-226 removed by iron filter backwash

295 gpm at 10 min. = 2,950 gal.

2,950 gal. x 3.785 x 80(composite)pCi/1 x 10^{-6} = 0.89 μCi/filter

Proportioned to regeneration cycle

0.89 μCi x 4 filters ÷ 1/14 = 0.025 μCi per regeneration

Ra-226 removed by zeolite softener backwash

13 minute backwash at 140gpm = 1,720 gal.

1,720 gal. x 3.785 x 7.8 pCi/1 x 10^{-6} = .050 μCi

Holstein (continued)

Ra-226 remaining in zeolite softener effluent

5 sample composite during softening cycle

65,000 gal. x 3.785 x 0.50 (composite) pCi/l x 10^{-6} = 0.123 µCi

Ra-226 removed by zeolite softener brine rinse

5 sample composite @ flows of 28 & 75 gpm during rinse

140 gal. x 3.785 x 210 pCi/l = 0.11 µCi
140 gal. x 3.785 x 700 pCi/l = 0.73
140 gal. x 3.785 x 1100 pCi/l = 0.58
375 gal. x 3.785 x 800 pCi/l = 1.14
375 gal. x 3.785 x 70 pCi/l = .10
Ra-226 removed by brine rinse 2.30 µCi

Table B-9

Radium-226 Distribution in Treatment Process
Webster City, Iowa
Lime Softening Plant
August 13, 1974

Ra-226 content in well water in 1.32 MGD flow

1.32 mg x 3.785 x 6.1 pCi/1 x 10^{-6} = 30.6 μCi/13 hrs

Ra-226 remaining in clarifier #1 effluent

660,000 gal x 3.785 x 1.9 pCi/1 x 10^{-6} = 4.74 μCi/13 hrs

Ra-226 remaining in clarifier #2 effluent

660,000 gal x 3.785 x 2.6 pCi/1 x 10^{-6} = 6.50 μCi/13 hrs

Average Ra-226 remaining in clarifier effluent

1.31 mg x 3.785 x (1.9+2.6)/2 pCi/1 x 10^{-6} = 11.2 μCi/13 hrs

Ra-226 removed in #2 sand filter backwash - 40 hrs operation

14,000 gal x 3.785 x 92 pCi/1 x 10^{-6} = 4.87 μCi (40 hrs run)

Ra-226 removed in #4 sand filter backwash - 27 hrs operation

14,000 gal x 3.785 x 91 pCi/1 x 10^{-6} = 4.82 μCi (27 hrs run)

Ra-226 removed by 4 filters 19.4 μ/Ci x $\frac{1.31 \text{ mg}}{4.55 \text{ mg}}$ = 5.6 μCi/1.31 mg

Ra-226 removed by lime sludge drawoff

2040# lime x 2.3 solids x 9.6% Dryweight x 8.33 = 5,860 gal sludge

5860 gal x 3.785 x 1114 average pCi/1 x 10^{-6} = 24.6 μCi

Ra-226 remaining in plant effluent

1.28 mg x 3.785 x 0.9 pCi/1 x 10^{-6} = 4.4 μCi to system

Table B-10

Radium-226 Distribution in Treatment Process
Webster City, Iowa
February 20, 1975

Ra-226 content in well water in 1.20 MGD flow

1.20 mg x 3.785 x 7.8 pCi/l x 10^{-6} = 35.4 μCi

Ra-226 remaining in clarifier #1 effluent

600,000 gal x 3.785 x 0.9 pCi/l x 10^{-6} = 2.04 μCi

Ra-226 remaining in clarifier #2 effluent

600,000 gal x 3.785 x 0.3 pCi/l x 10^{-6} = 0.68 μCi

Ra-226 remaining in clarifier effluent

1,200,000 gal x 3.785 x (0.9+0.3)/2 pCi/l x 10^{-6} = 2.72 μCi

Ra-226 removed in #3 filter backwash

14,000 gal x 3.785 x 50 pCi/l x 10^{-6} = 0.26 μCi

Approximately equal to radioactivity removal by 4 filters/day

Ra-226 removed by lime sludge drawoff

7140# Dryweight removed at 9.74% dryweight x 8.33 = 8,800 gal

8,800 gal x 3.785x 980 average pCi/l x 10^{-6} = 32.6 μ/Ci

Ra-226 remaining in plant effluent

1.20 mg x 3.785 x 0.3 pCi/l x 10^{-6} = 1.36 μCi to system

Table B-11

RADIUM-226 DISTRIBUTION IN TREATMENT PROCESS
West Des Moines, Iowa

LIME-SODA ASH SOFTENING PLANT
August 1, 1974

Ra-226 content in well water in 2.57 MGD Flow

2.57 MG x 3.785 x 9.3 pCi/l x 10^{-6} = 91 μCi

Ra-226 content remaining in clarifier effluent

2.57 MG x 3.785 x 2.6 pCi/l x 10^{-6} = 24.6 μCi

Ra-226 content in clarifier #1 lime sludge drawoff

8,700 gallons of 14.5% DW sludge

8,700 gallons x 3.785 x 2,300 pCi/l x 10^{-6} = 76.0 μCi

Ra-226 content in sand filter backwash

Backwash 1.2% of day's pumpage

2.57 MG 1.2% x 3.785 x 6.3 pCi/l = 0.73 μCi

Ra-226 remaining in filter effluents

2.57 MG x 3.785 x 2.3 pCi/l x 10^{-6} = 22.6 μCi

APPENDIX

SECTION C

CAPITAL AND OPERATING COSTS

Table C-1

Water Capital and Operating Costs
Annual Report to State Auditor
Greenfield

	1971	1972	1973
Total Revenue	$59,606	$117,598	$123,909
Expenses			
Plant Operation	14,814	14,133	15,791
Maintenance		1,088	
Distribution Operation	4,939	3,142	5,435
Maintenance		749	
Accounting and Collecting	1,687	1,719	1,642
Administration	6,307	7,612	7,290
Debt Service	15,716	16,210	15,760
Capital Investment	15,322	23,754	28,207
Miscellaneous			273
Total Expenses	$58,785	$68,407	$74,398
Annual Pumpage MG/yr (1)	64.9	65.6	66.8
Cost ¢/1000 gal (2)	91¢	104¢	111¢
Remarks			
(1) Percent of RO Production	20%	21%	30%

(2) Water cost ¢/kgal for 1970 prior to RO treatment was 83¢.

Table C-2

Water Capital and Operating Costs
Annual Report to State Auditor
Adair

	1971	1972	1973
Total Revenue	$31,269	$30,374	$75,903 (1)
Expenses			
Plant Operation	$6,180	$11,243	$8,140
Maintenance	2,506		8,415 (2)
Distribution Operation	1,775	4,785	1,900
Maintenance	2,780		3,385
Accounting and Collecting	839	919	495
Administration	210		
Debt Service	12,625	12,454	12,795
Capital Investment	2,480	2,211	84,399 (3)
Miscellaneous	552	746	782
Total Expenses	$29,947	$32,358	$120,311
Annual Pumpage MG/yr	20.9	24.5	NA
Cost ¢/1000 gal	143¢	132¢	

Remarks

(1) Includes $40,000 bond sales for water main extensions.

(2) Includes repair on greensand filter.

(3) Major portion is for water main extension to serve industry and new housing subdivision.

Table C-3

Water Capital and Operating Costs
Annual Report to State Auditor
Stuart

	1971	1972	1973
Total Revenue	$28,634	$41,212	$44,437
Expenses			
Plant Operation	7,376	6,455	9,465
Maintenance	3,816	271	52
Distribution Operation		930	5,325
Maintenance		280	
Accounting and Collecting	81	40	
Administration	325	1,336	1,306
Debt Service	7,720	7,750	7,537
Capital Investment	11,102	15,029	8,868
Miscellaneous	784	8,852	12,994
Total Expenses	$31,204	$40,943	$45,547
Annual Pumpage MG/yr	48.6	56.3	57.7
Cost ¢/1000 gal	64	73	79
Remarks			

Table C-4

Water Capital and Operating Costs
Annual Report to State Auditor
Eldon

	1971	1972	1973
Total Revenue	$23,447	$22,641	$23,915
Expenses			
Plant Operation	$9,674	$10,286	$11,034
Maintenance	127	623	562
Distribution Operation	256	295	483
Maintenance	2,200	6,838	3,834
Accounting and Collecting	1,377	916	575
Administration		46	77
Debt Service	4,579	4,268	4,679
Capital Investment	2,247	615	5,259
Miscellaneous			280
Total Expenses	$20,460	$23,887	$26,783
Annual Pumpage MG/yr	34.8	36.9	29.3
Cost ¢/1000 gal	59	65	91
Remarks			

Table C-5

Water Capital and Operating Costs
Annual Report to State Auditor
Estherville

	1971	1972	1973
Total Revenue	$216,402		$375,758
Expenses			
Plant Operation	$99,185		$118,078
Maintenance	8,598		14,724
Distribution Operation	2,534		20,082
Maintenance	7,634		12,059
Accounting and Collecting	6,826		23,624
Administration	9,274		30,976
Debt Service	29,885		0
Capital Investment	27,590		62,567
Miscellaneous	4,807		7,336
Total Expenses	$196,333		$289,446
Annual Pumpage MG/yr	408.5		436.0
Cost ¢/1000 gal	46		66
Remarks			

Table C-6

Water Capital and Operating Costs
Annual Report to State Auditor
Grinnell

	1971	1972	1973
Total Revenue	$184,634	$174,864	$560,478 (1)
Expenses			
Plant Operation	$99,185	$93,610	$87,776
Maintenance	8,597	2,127	14,902
Distribution Operation	2,534	3,247	1,347
Maintenance	7,634	10,230	15,386
Accounting and Collecting	6,826	7,653	6,506
Administration	9,724	9,823	6,164
Debt Service	29,885	29,235	49,118
Capital Investment	27,590	22,551	122,859 (2)
Miscellaneous	8,086	7,625	10,249
Total Expenses	$200,061	$186,101	$314,307
Annual Pumpage MG/yr	NA	416	407
Cost ¢/1000 gal		44	77

Remarks

(1) Includes $317,050 bond sale for capital out of new #8 Jordan well, pump and connecting main to treatment plant.

(2) Capital outlay for cost of watermain extensions.

Table C-7

Water Capital and Operating Costs
Annual Report to State Auditor
Holstein

	1971	1972	1973
Total Revenue	$34,172	$35,226	$35,549
Expenses			
Plant Operation	$17,134	$18,170	$20,105
Maintenance			
Distribution Operation		1,588	
Maintenance	1,636		58
Accounting and Collecting	170		
Administration	165		
Debt Service	5,330	5,190	6,050
Capital Investment	3,299	10,330	8,821
Miscellaneous	2,458	847	1,951
Total Expenses	$30,192	$36,125	$36,985
Annual Pumpage MG/yr	51.6	50.1	NA
Cost ¢/1000 gal	59	72	
Remarks			

Table C-8

Water Capital and Operating Costs
Annual Report to State Auditor
Webster City

	1971	1972	1973
Total Revenue	$201,302	$294,909	$257,606
Expenses			
Plant Operation	$69,998	$73,147	$77,812
Maintenance	18,931	16,775	26,801
Distribution Operation	3,731	4,228	2,765
Maintenance	21,862	24,004	33,926
Accounting and Collecting	21,088	22,166	23,075
Administration	7,430		13,061
Debt Service	41,653	42,648	45,508
Capital Investment	$55,849	$124,057	37,827
Miscellaneous	5,610	6,443	9,121
Total Expenses	$246,152	$313,468	$269,896
Annual Pumpage MG/yr	463	486	507
Cost ¢/1000 gal	53	64	53
Remarks			

Table C-9

Water Capital and Operating Costs
Annual Report to State Auditor
West Des Moines

	1971	1972	1973
Total Revenue	$627,381	$900,359	$986,827
Expenses			
Plant Operation	$122,671	$137,044	$166,509
Maintenance	2,197	8,073	4,365
Distribution Operation	22,225	20,973	36,534
Maintenance	3,114	2,579	1,184
Accounting and Collecting	31,988	32,914	32,510
Administration	117,058	161,030	201,263 (1)
Debt Service	126,430	164,610	164,203
Capital Investment	824,449	844,196 (2)	224,913
Miscellaneous	14,009	216,422	197,770
Total Expenses	$1,264,141	$1,587,841	$1,029,251
Annual Pumpage MG/yr	520	613	683
Cost ¢/1000 gal	243¢	259¢	151¢ (3)

Remarks

(1) Includes sewer rental receipts.

(2) Capital outlays for plant improvements.

(3) Large capital improvement costs applied to these years.

APPENDIX

SECTION D

RADIUM-226 ANALYSIS MODIFICATIONS & ACCURACY

Precision and Accuracy of Radium-226 Analysis

For each group of water samples analyzed for total radium, a reference sample was prepared simultaneously. The average recovery of radium-226 from the reference samples was 93.5%.

The intrinsic precision (standard deviation) of this method for a single operator is about 5%. The overall percision (S_t) of a particular analysis is found by combining the standard deviation of counting (S_a) with the intrinsic precision (S_m) as follows:

$$S_t = S_m^2 + S_a^2$$

The overall precision was computed to be within approximately ± 10% above 1.0 pCi/l and ± 0.1 pCi/l below 1.0 pCi/l.

This method (ASTM D 2460-70) covers the separation of dissolved radium from water for the purpose of measuring its radioactivity. The lower limit of concentration to which this method is applicable is quoted as 1 pCi/l.

Additional Radium-226 in Water Analytical Procedures

Ref: ASTM D 2460-70 Standard Method of Test for Radionuclides of Radium in Water.

Additional descriptions of analytical procedures used follow:

Step 10.2 For many of the samples, the pink indicator did not work satisfactorily. The only indication was the forming of a precipitate.

Step 10.4 When distilled water is added to the precipitate to dissolve it, add two drops of phenolphthalein solution and add the NH_4OH until solution is alkaline.

Step 10.6 Final precipitate is transferred to a counting planchet with small amount of distilled water (near zero count), dried with 2 ml acetone and three drops of lucite solution in acetone. A 2" dia. x 0.018" thick x ¼" deep stainless stell planchet was used.

Counting Procedure:

Samples are counted for 100 minutes starting a minimum of 24 hours after ingrowth start time. They are counted three time approximately 29 hours apart.

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The sample count is corrected for ingrowth from a chart prepared using a 50 pCi sample of Radium-226 counted for 30 days.

A counter efficiency char was prepared likewise from a 50 pCi sample of Radium-226 aged for 30 days.

Gross Alpha Radioactivity in Water Analytical Procedures

Ref: Standard Methods for the Examination of Water and Wastewater, 13th Ed.

Additional descriptions of analytical procedures used are as follows:

1. The sample volume was chosen so as not to exceed 4 mg/cm^2 of counting area.

2. All samples, except those laden heavy with sludge, were acidified with HCl.

3. Samples with sediment were centrifuged with the supernate used directly (for Radium-226 determination supernate was filtered). After preparation, the samples were heated to drive out corrosive compounds. This process introduces some radioactivity loss.

4. Sludge sediment was dried, weighed and measured amounts were dissolved in distilled water with HCl.

5. For solid samples.

    a. Anthrafilt was crushed and leached in distilled water with HCl.

    b. The resins were crushed and leached in distilled water with HNO_3 (The same process with HCl proved less effective). The resins did not dissolve in any solvent available in the laboratory.

APPENDIX

SECTION E

SALT UTILIZATION BY ION EXCHANGE

Table E-1

Salt Utilization by Ion Exchange - Summary

	Eldon	Estherville	Grinnell	Holstein
Raw water hardness mg/l	375	915	385	920
Raw water sodium mg/l	270	60	120	110
Softened water sodium mg/l	375	430	290	520
Gallons per softening cycle	106,000	130,000	200,000	55,000
Pounds salt dosage per cycle	600	2,040	1,454	904
Pounds salt dosage per million gallons	5,660	15,700	7,270	16,400
Pounds salt added by regeneration	681	1,850	870	1,970
Total chloride added to water (lbs x 35 ÷ 58)	411	1,130	782	1,860
Total sodium added to water (lbs x 23 ÷ 58)	270	745	345	780
Sodium increase in effluent (softened - raw)	105	370	170	410
Sodium not used in regeneration (mg/l increased ÷ mg/l dosage)	165	375	175	370
Sodium efficiency (increase ÷ dosage)	39%	50%	50%	47%
Kgr hardness removed/regeneration (gallons x grains hardness)	2,330	7,000	4,500	2,800
Pounds hardness removed/regeneration (kgr ÷ 7,000 gr/lb)	332	1,000	680	400
Pounds hardness removed/1,000,000 gal (pounds ÷ gallons/regeneration)	3,140	7,700	3,400	7,280
Salt efficiency (lbs utilized ÷ lbs dosage)	55%	50%	47%	44%
Ratio - salt dosage ÷ hardness	1.8	2.0	2.1	2.2

Table E-2

Salt Utilization by Ion Exchange
Eldon, Iowa

Salt dosage - 600 lbs per 106,000 gallons cycle
- 5660 lbs per million gallons
- 680 mg/l NaCl added by regeneration

Total Chloride added to water $\frac{680 \times 35}{58}$ = 410 mg/l

No chloride increase in effluent during softening cycle

Total sodium added to water $\frac{680 \times 23}{58}$ = 270 mg/l

Sodium increase in effluent 375 - 270 = 105 mg/l Na
Sodium not utilized in brine regeneration = 165 mg/l Na

Sodium efficiency $\frac{\text{105 mg/l increase}}{\text{270 mg/l dosage}}$ = 39%

Hardness removed 106,000 gal x 22 gains hardness = 2,330 Kgr

Pounds hardness removed $\frac{\text{2330 Kgr}}{\text{7000 gr/lb}}$ = 332 lbs per regeneration

Pounds hardness removed $\frac{\text{332 lbs x 1 MG}}{\text{106,000 gal.}}$ = 3140 lbs/million gallons

Salt efficiency $\frac{\text{3140 lbs utilized}}{\text{5660 lbs dosage}}$ = 55%

Table E-3

Salt Utilization by Ion Exchange
Holstein, Iowa

Salt dosage - 904 lb per 55,000 gallons cycle
- 16400 lb per million gallons
- 1970 lb NaCl added by regeneration

Total Chloride added to water $\frac{1970 \times 55}{58} = 1860$ mg/l

No chloride increase in effluent during softening cycle

Total sodium added to water $\frac{1860 \times 23}{58} = 780$ mg/l

Sodium increase in effluent 520 - 110 = 410 mg/l Na

Sodium not utilized in brine regeneration = 370 mg/l Na

Sodium efficiency $\frac{\text{370 mg/l increase}}{\text{780 mg/l dosage}} = 47\%$

Hardness removed 55,000 gal x 51 grains hardness = 2,800 Kgr

Pounds hardness removed $\frac{\text{2800 Kgr}}{\text{7000 gr/lb}}$ = 400 lb per regeneration

Pounds hardness removed $\frac{\text{400 lb} \times \text{1 MG}}{55{,}000}$ = 7280 lb/million gallons

Salt efficiency $\frac{\text{7280 lb utilized}}{\text{16400 lb dosage}} = 44\%$

Table E-4

Salt Utilization by Ion Exchange
Estherville, Iowa

Salt dosage - 2040 lb per 130,000 gallons cycle
- 15700 lb per million gallons
- 1850 lb NaCl added by regeneration

Total Chloride added to water $\frac{1850 \times 35}{58} = 1130$ mg/l

No chloride increase in effluent during softening cycle

Total sodium added to water $\frac{1850 \times 23}{58} = 745$ mg/l

Sodium increase in effluent 430 - 60 = 370 mg/l Na

Sodium not utilized in brine regeneration = 375 mg/l Na

Sodium efficiency $\frac{375 \text{ mg/l increase}}{745 \text{ mg/l dosage}} = 50\%$

Hardness removed 130,000 gal × 53 grains hardness = 7,000 Kgr

Pounds hardness removed $\frac{7000 \text{ Kgr}}{7000 \text{ gr/lb}} = 1000$ lb per regeneration

Pounds hardness removed $\frac{1000 \text{ lb} \times 1 \text{ MG}}{130,000 \text{ gal}} = 7700$ lb/million gallons

Salt efficiency $\frac{7700 \text{ lb utilized}}{15400 \text{ lb dosage}} = 50\%$

Table E-5

Salt Utilization by Ion Exchange
Grinnell, Iowa

Salt dosage - 1454 lb per 200,000 gallons cycle
- 7270 lb per million gallons
- 870 mg/l NaCl added by regeneration

Total Chloride added to water $\frac{870 \times 55}{58}$ = 782 mg/l

No chloride increase in effluent during softening cycle

Total sodium added to water $\frac{870 \times 23}{58}$ = 345 mg/l

Sodium increase in effluent 290 - 120 = 170 mg/l Na

Sodium not utilized in brine regeneration = 175 mg/l Na

Sodium efficiency $\frac{\text{170 mg/l increase}}{\text{345 mg/l dosage}}$ = 50%

Hardness removed 200,000 gal x 22.2 grains hardness = 4,500 Kgr

Pounds hardness removed $\frac{\text{4500 Kgr}}{\text{7000 gr/lb}}$ = 680 lb per regeneration

Pounds hardness removed $\frac{\text{680 lb x 1 MG}}{\text{200,000}}$ = 3400 lb/million gallons

Salt efficiency $\frac{\text{3400 lb utilized}}{\text{7270 lb dosage}}$ = 47%

Appendix F

Radiation Exposure Rates in Water Treatment Plants

Measurements were made in seven of the plants studied to detect elevated radiation exposure rates. These measurements were made to check on possible hazards to plant personnel and to find locations in the plant equipment and piping where radium might be concentrating.

No elevated exposure rates were detected at the reverse osmosis and lime-soda ash softening plants. Elevated exposure rates were detected in the ion-exchange softeners and in the anthracite filters at three sodium cation exchange softening plants where measurements were made and at the greensand iron removal plant at Adair.

Adair

A survey of the plant indicated elevated levels at the greensand tank. A profile of the tank (Figure F-1) indicates that the majority of the radioactivity is around the tank centerline. The greensand media had been regenerated the previous day and was about half-way through a cycle. The natural background exposure rate around the plant was about 11 μR/hr.

Estherville

Elevated exposure rates were found throughout the plant. Exposure rates inside the main equipment room, at working level, were 3 to 13 μR/hr above a natural background of 7 μR/hr. An exposure rate profile at the surface of the #2 zeolite tank (Figure F-2) indicated that the greatest concentration of radioactivity is near the bottom of the tank, near the interface of the zeolite and the sand-gravel base. Profiles of the other three zeolite tanks produced similar results. No change was noted in the exposure rates when the zeolite media were regenerated, indicating that a portion of the radioactivity permanently remains on the media.

Grinnell

Elevated exposure rates of 3 μR/hr above the natural background rate were detected on the surfaces of the zeolite tanks. The maximum exposure rate was detected at the zeolite-gravel interface near the bottom of the tanks.

Holstein

Elevated exposure rates were found on the surfaces of the zeolite tanks and the anthracite filter tank (Figure F-3). The maximum exposure rates were detected near the bottom of the zeolite tanks and in the top half of the filter media (the water flow is downward). The natural background exposure rate around the plant is about 10 μR/hr.

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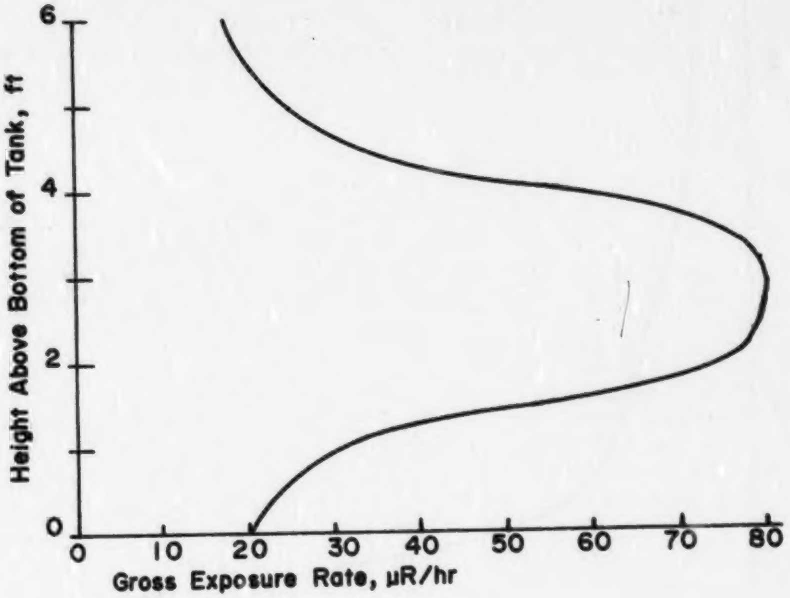

Figure F-1 Exposure Rates on Surface of Greensand Tank, Adair, Iowa

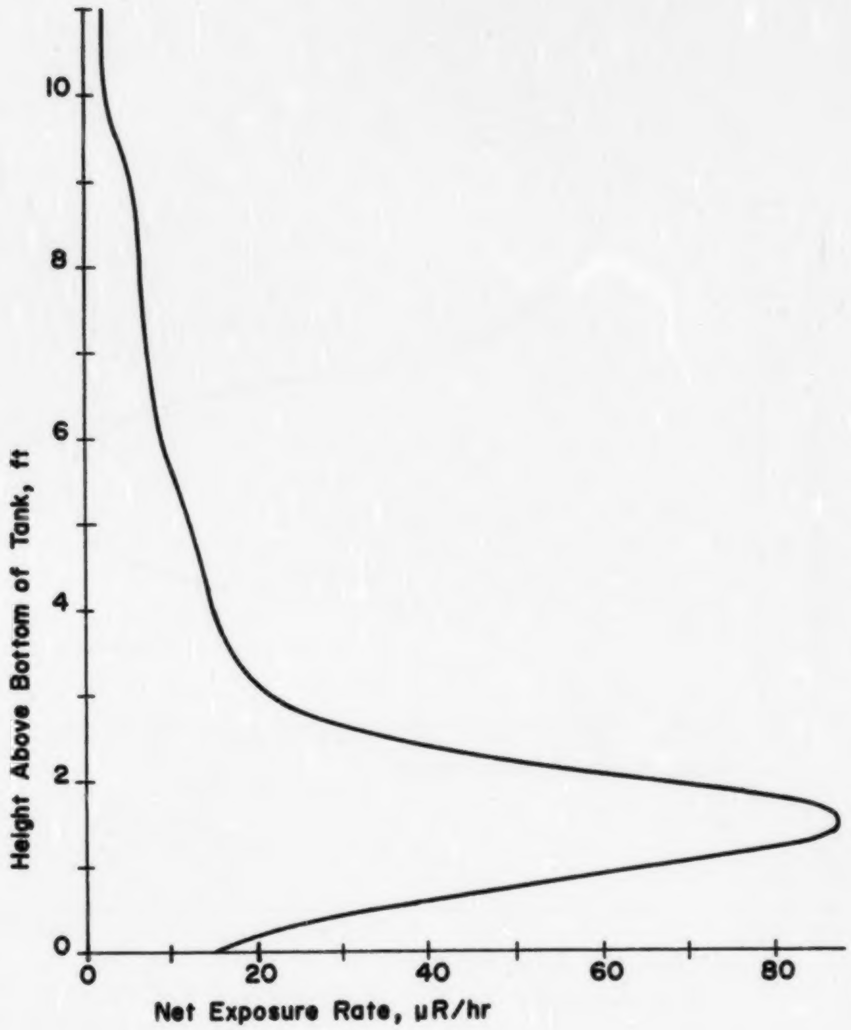

Figure F-2 Exposure Rates on Surface of Zeolite Tank, Estherville, Iowa

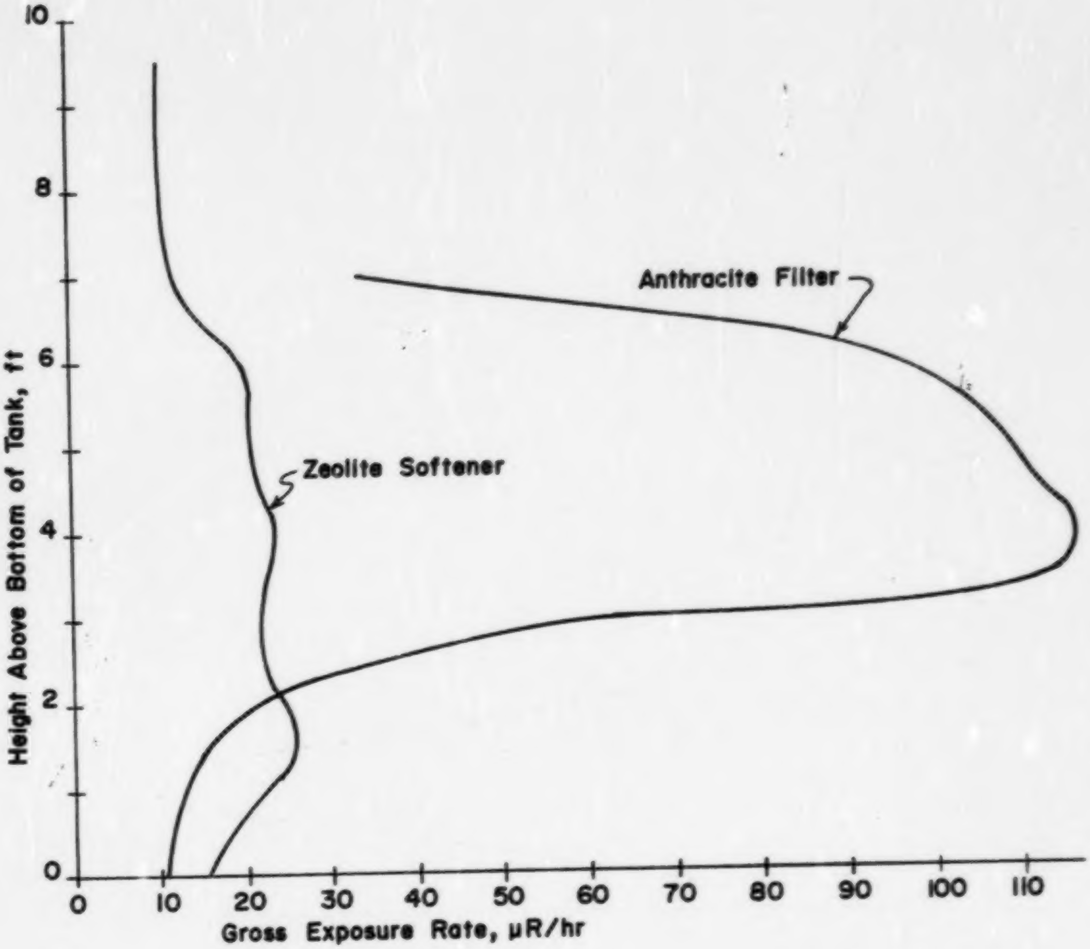

Figure F-3 Exposure Rates on Surface of Zeolite Tank and Anthracite Filter, Holstein, Iowa

This initial investigation indicates that exposure rates in the water treatment plants were not significant to employee safety. However, further investigation of the exposure level during cleaning of filters and changing of anthrafilt and ion-exchange media should be carried out to determine whether a hazard exists under these circumstances.